Research Note 84-68

AD A139782

PSYCHOLOGICAL RESEARCH ON ADVANCED TERRAIN REPRESENTATION: FORMATTING THE VISUAL MATERIAL

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March 1984

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Research Note 84-68	2. GOVT ACCESSION NO. AD A139 782	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PSYCHOLOGICAL RESEARCH ON ADVANCED TERRAIN REPRESENTATION: FORMATTING THE VISUAL MATERIAL		5. TYPE OF REPORT & PERIOD COVERED Research Note
		6. PERFORMING ORG. REPORT NUMBER DDI/PR 82-9-331
7. AUTHOR(s) Robert N. Kraft John F. Patterson Nancy B. Mitchell		8. CONTRACT OR GRANT NUMBER(s) MDA903-81-C-0568
9. PERFORMING ORGANIZATION NAME AND ADDRESS Decisions and Designs, Inc. Suite 600, 8400 Westpark Drive, P.O. Box 907 McLean, VA 22101		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q162717A790
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Research Institute 5001 Eisenhower Avenue Alexandria, VA 22333		12. REPORT DATE March 1984
		13. NUMBER OF PAGES 112
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

See also DDI/PR 82-10-331

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Military training
Training devices
Simulation
Computerized simulation
Videodiscs
Terrain
Travel Coherence
Experimentation
Distance perception
Viewing Angle
Steepness perception

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes an empirical investigation which was done to guide the development of a videodisc based system that will provide free travel from a ground-level perspective within a simulated environment. The Advanced Terrain Representation (ATR) system will be based on a generalization of surrogate travel. The purpose of conducting this psychological research was to —

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provide the bounds of perceptual acceptability for guiding subsequent technological development. Ideally, ATR would present a complete and veridical representation of the natural tactical environment; however, because of storage constraints inherent in videodisc technology, the amount of information which can be presented is limited. Psychological research was conducted to help produce a compelling, pedagogically effective system within these constraints. The primary research question was as follows: what is the most efficient way to represent a large piece of terrain in a perceptually informative fashion? A short summary of the findings indicate that the camera lens angle at which a picture is taken drives the estimation of distances from the "observer" to a point in the picture, but not the distance between two points in a photograph; the acceptable "jump size" is a function of the type of terrain; and the number of acceptable viewing and travel directions are narrowly constrained.

SUMMARY

This report describes an empirical investigation which was done to guide the development of a videodisc based system that will provide free travel from a ground-level perspective within a simulated environment (Patterson, Kraft, and Buede, 1982). The Advanced Terrain Representation (ATR) system will be based on a generalization of surrogate travel developed by Lippman (1980). The purpose of conducting this psychological research was to provide the bounds of perceptual acceptability for guiding subsequent technological development. Ideally, ATR would present a complete and veridical representation of the natural tactical environment; however, because of storage constraints inherent in videodisc technology, the amount of information which can be presented is limited.

This psychological research was conducted to help produce a compelling, pedagogically effective system within these constraints. The primary research question was as follows: what is the most efficient way to represent a large piece of terrain in a perceptually informative fashion?

The following format variables were examined empirically:

1. Angle of View
2. Jump Size
3. Number of Viewing Directions
4. Number of Travel Directions

These variables were selected for empirical investigation because they represent the basic building blocks for constructing a videodisc-based representation of open-field terrain and because they carry with them uncertainty that may only be

resoluble through psychological experimentation (Kraft and Patterson, 1981).

Angle of view refers to the angular size of the photograph used to create the visual display for the system and is directly related to the focal length of the camera lens. Angle of view typically ranges from 30° and below (telephoto) to 45° ("normal") up to 90° (wide angle) and beyond. The wider the angle, the more information that can be contained in the photograph, and the more the objects in the photograph appear stretched out.

Jump size refers to the distance between the center of one grid unit and the center of the next grid unit on a particular path of travel. The number of viewing directions refers to the number of discrete views resulting in a 360° pivot around the center of any grid unit. Finally, the number of travel directions is simply the number of discrete directions of straight-line travel from any given grid unit.

Four separate experiments were conducted. In Experiment 1, distance perception was examined as a function of viewing angle. Distance perception along the depth plane was significantly affected by viewing angle; the wider the angle, the greater the perceived distance. It was found that a viewing angle of 90° appears to be the widest distortion-free angle, closely approximating distance perception in the real world.

Experiment 2, the perception of hills, demonstrated that viewing angle significantly affected steepness perception, and further, that visual travel over terrain interacted with perceived steepness. However a 90° viewing angle would not create any more distortion or variability than any of the other viewing angles being tested. This experiment also replicated the major finding of the first experiment: widening the angle of view increases distance estimates. In addition, Experiment 2

results demonstrated that height perception can be affected by viewing angle: when viewers were visually on a hill, viewing angle significantly affected height perception; when the hill was viewed from a distance, perceived height remained constant across the different viewing angles.

Two format variables were examined in Experiment 3: jump size and number of viewing directions in two types of terrain. In lightly wooded terrain, visual travel remained coherent up to jump sizes of 20m, but began to fall apart at 30m. At a jump size of 40m, travel coherence was unacceptably poor. These results suggested, then, that the maximum allowable jump size for lightly wooded terrain should be 25m. Pivots remained coherent with successive angular displacements of 15°, but became increasingly incoherent with displacement of 22.5° and 30°. These results suggested that the maximum allowable angular displacement in lightly wooded terrain should be 15° and thus, twenty-four viewing directions would be needed to specify a complete 360° pivot.

In open terrain, visual travel remained coherent up to jump sizes of 35m. At 55m, travel coherency broke down, but at 75m, a high degree of travel coherence returned. It appears that the greater the jump size, the greater the likelihood that a significant landmark will disappear between successive views, or that the general terrain characteristics will change from from one view to the next. It was still possible to maintain coherent linear travel with a jump size of 75m, given a highly homogeneous stretch of terrain. Given the potential loss of coherence that can occur, however, the maximum allowable jump size in open terrain was set at 50m. Pivot coherence in open terrain was consistently high across all the levels of angular displacement that were tested. A 30° angular displacement was as coherent as a 7.5° angular displacement. Thus, the maximum allowable angular displacement in open terrain should be set at

30°, indicating that twelve viewing directions would be needed to specify a complete 360° pivot.

In Experiment 4, the minimum number of travel directions needed to provide the ATR user with a sense of free travel was examined. Subjects viewed film sequences representing linear travel along a path which was oblique to the desired direction of travel. The results suggest that for a 90° viewing angle, subjects will become uneasy about going astray when the angular discrepancy between the desired and actual direction of travel is approximately 15°, indicating an upper limit of twenty-four travel directions. Subjects will experience a strong need to correct their travel path when the angular discrepancy reaches approximately 22.5°, indicating a lower limit of sixteen travel directions. These results apply to both lightly wooded and open terrain.

Finally, the jump size, travel and viewing directions which one would select for implementation are dependent not only on the results of this research but on the overall system parameters such as minimum and maximum vehicle speed, the type of hardware that is chosen, i.e., frame buffer versus no frame buffer, the intended use of the system, the developmental budget, and the final cost to the user. Each of these factors is given complete consideration in Patterson, Kraft, Buede and Mitchell (1982).

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PSYCHOLOGICAL RESEARCH ON ADVANCED TERRAIN REPRESENTATION: FORMATTING THE VISUAL MATERIAL

1.0 INTRODUCTION

This document describes the empirical investigation of critical perceptual issues involved in developing a videodisc-based system for Advanced Terrain Representation (ATR). The system will generalize the techniques of "surrogate travel" developed by Lippman (1980) in order to provide free travel from a ground-level perspective within a simulated environment (Patterson, Kraft, and Buede, 1982). Specifically, ATR will provide the visual basis for developing a tactics training system for tank platoon leaders and commanders. In general, ATR will furnish a realistic videodisc-based representation of free travel over natural terrain, from a ground perspective.

Ideally, the ATR system would present a complete and veridical representation of the natural tactical environment; however, because of storage constraints inherent in videodisc technology, the amount of information which can be presented is limited. Therefore, in order to produce a compelling, pedagogically effective system, it is necessary to ascertain optimal ways of circumventing the problems associated with these constraints. The psychological research described herein provides some of the necessary information for solving these problems.

1.1 Research Focus

Development of the proposed system involves four general components: (1) the source of the visual material (e.g., actual

terrain, terrain boards, architectural models, or computer-generated imagery); (2) storage of the visual data; (3) the method of generating and using intervisibility data; and (4) display of the information to the user. The empirical research described in this document, however, focused on only a portion of the entire system development process. Specifically, it focused on the mapping of the source material to the data representation, as shown in Figure 1-1. That is, the research examined tactically motivated perceptual issues related to the format of the visual material. The primary question was: what is the most efficient way to represent a large piece of terrain in a perceptually coherent and tactically informative fashion? In fact, the purpose of conducting this psychological research was to provide the bounds of perceptual acceptability for guiding subsequent technological development.

1.2 Format Variables

The process by which the critical format variables were identified and defined is described, in detail, in Kraft and Patterson (1981), and will only be summarized here. Five variables were identified as being fundamental to the composition and format of information on the videodisc:

1. Angle of View
2. Jump Size
3. Number of Viewing Directions
4. Number of Travel Directions
5. Image Resolution

The first four of these variables were selected for empirical investigation because they represent the basic building blocks for constructing a videodisc-based representation of open-field terrain and because they carry with them uncertainty that may

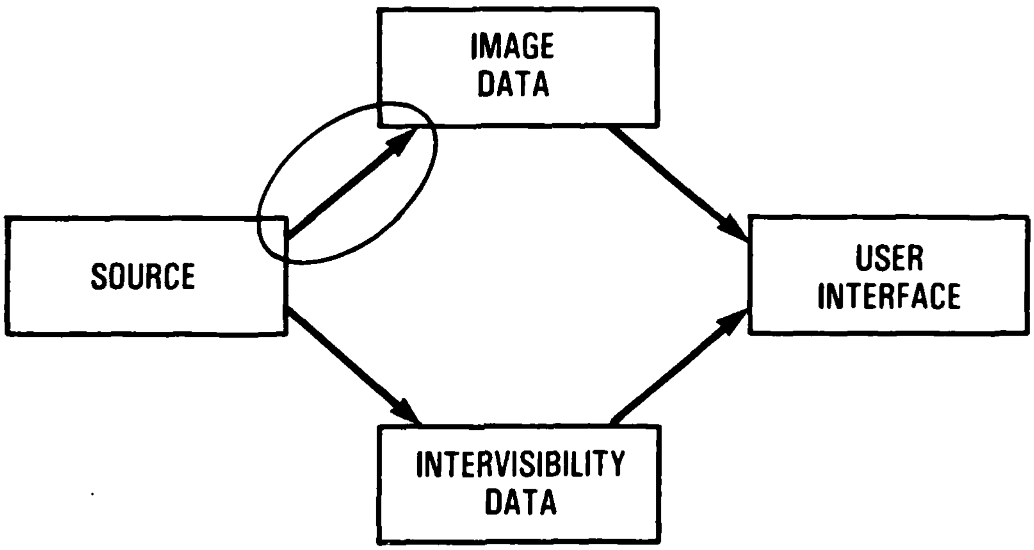

Figure 1-1
FOCUS OF PROPOSED PSYCHOLOGICAL RESEARCH

only be resoluble through psychological experimentation (Kraft and Patterson, 1981). It was decided that the fifth variable on this list, image resolution, did not warrant formal empirical investigation, but rather could be investigated through informal observation.

Angle of view refers to the angular size of the photograph used to create the visual display for the system and is directly related to the focal length of the camera lens. Angle of view typically ranges from 30° and below (telephoto) to 45° ("normal") up to 90° (wide angle) and beyond. (In a typical 35mm camera, a lens with a focal length of 50mm represents a normal 47° angle of view. Longer focal lengths, 90mm and longer, produce narrow, telephoto viewing angles. Shorter focal lengths, 35mm and shorter, produce wide angles of view.) The wider the angle, the more information that can be contained in the photograph, and the more the objects in the photograph appear stretched out.

Jump size refers to the distance between the center of one grid unit and the center of the next grid unit on a particular path of travel; the number of viewing directions refers to the number of discrete views resulting in a 360° pivot around the center of any grid unit; the number of travel directions is simply the number of discrete directions of straight-line travel from any given grid unit. Note that the number of viewing directions would be a multiple of the number of travel directions. That is, pivoting may demand a finer resolution than traveling. For example, the system may allow eight directions of travel, but sixteen directions of view. Image resolution refers specifically to the number of picture elements (pixels) used to present the visual displays; the fewer the pixels, the lower the resolution.

1.3 Research Plan

Four separate psychological experiments were conducted, investigating the first four format variables identified in the previous section. The results from these experiments should provide a sound basis for helping to translate these "format variables" into "system parameters," as shown in Figure 1-2.

Experiments 1 and 2 specify the focal length of the lens to be used in photographing the terrain. Experiment 3 provides the upper bound for jump size and number of viewing directions across different types of terrain. Experiment 4 empirically specifies the minimum number of travel directions that provides the user with an experience of free travel.

Sections 2 through 5 of this report describe the four experiments. Section 6 presents general conclusions and recommendations based on the results of the experimentation and consideration of technological concerns.

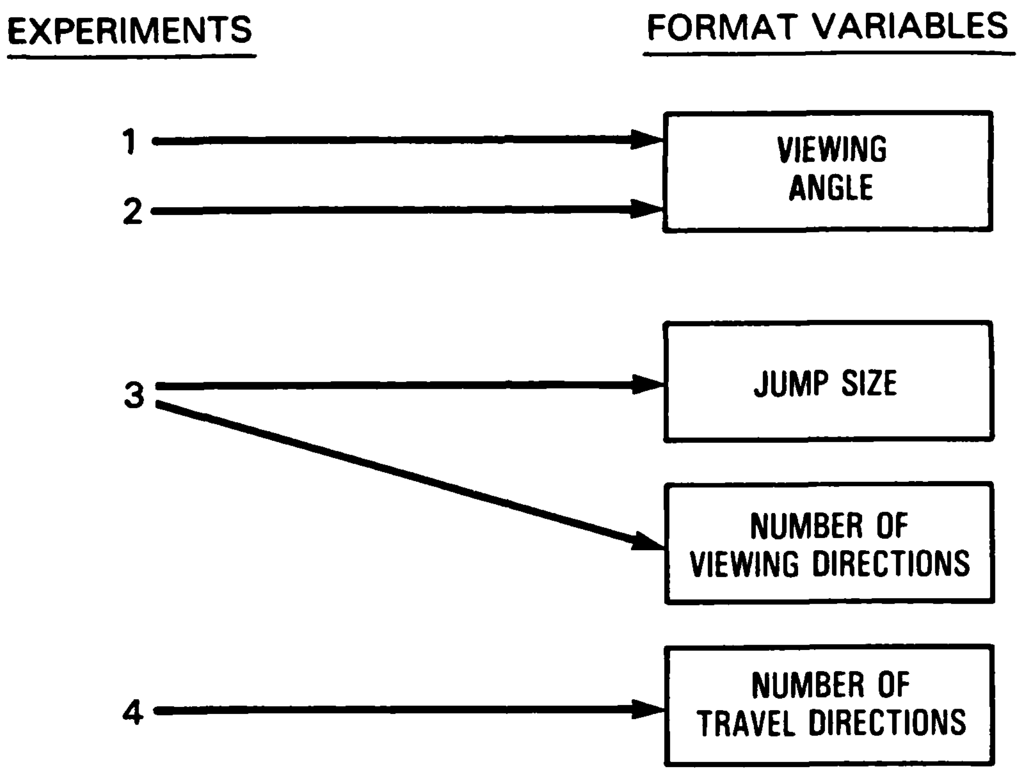

Figure 1-2
EMPIRICAL SPECIFICATION OF THE FORMAT VARIABLES

2.0 EXPERIMENT 1: THE EFFECT OF VIEWING ANGLE ON PERCEIVED DISTANCE IN STATIC SCENES

2.1 Abstract

Distance perception of objects depicted in color slides was examined as a function of viewing angle. Subjects viewed slides depicting different types of terrain and estimated the distance to target objects located at three different levels of depth in the scene. With some of the slides, subjects also estimated the distance between two depicted objects. Each scene was photographed at four different sizes of pictorial viewing angle: 48°, 72°, 84° and 104°. Distance perception along the pictorial depth plane was significantly affected by viewing angle; the wider the angle, the greater the perceived distance. Perceived distance between two depicted objects, however, was unaffected by changes in viewing angle.

2.2 Background

2.2.1 Viewing Angle and Distance Perception - When designing a system to support visually guided behavior, it is highly desirable to present the user with the widest possible view in the visual display. A wide angle of view allows the user to scan naturally more of his simulated environment and may actually permit more flexibility with other format variables, i.e., jump size, number of views, and number of travel directions. Thus, a wide angle of view facilitates the user's interaction with the system as well as increasing the efficiency of coverage for a given piece of terrain.

Widening the viewing angle, however, may alter the user's perception of distances in the visual display. Indeed,

the literature concerned with the aesthetics of filming posits several principles regarding the relationship between pictorial viewing angle and perceived distance (e.g., Kracauer, 1960; Mascelli, 1965; Spottiswoode, 1967; Metz, 1974; Andrew, 1976; Giannetti, 1976; Monaco, 1977). The general effects are as follows. The angle of view of a visual display relates directly to the focal length of the lens used to photograph the environment for that display. The shorter the focal length, the wider the angle of view (Miller, 1972; Coynik, 1974). A "normal" lens for a 35mm camera is one with a focal length of 50mm and a viewing angle of approximately 47°. With such a lens, depicted objects are distributed the way they would appear to the naked eye. A telephoto or "narrow" lens is one with a focal length of more than 90mm and a viewing angle of less than 30°. A telephoto lens creates a shallow perspective; objects at varying distances appear much closer than they actually are. A wide angle lens is one with a focal length of less than 35mm and a viewing angle of more than 60°. The wide lens causes objects to appear smaller and farther away than they actually are (Mascelli, 1965; Coynik, 1974; Giannetti, 1976).

It should be noted that, although photographers, cinematographers, movie directors, and film theorists, are rather certain about these principles of visual perspective, there is, at present, no empirical evidence to quantify the effects of viewing angle or even to validate that it is a psychologically real phenomenon. The primary goal in this proposed study is to quantify the effect of varying viewing angle on perceived distance in order to help determine which particular focal length lens to use while filming a selected piece of terrain.

2.2.2 Distance Perception in the Natural Environment - After empirically describing how viewing angle affects distance estimation, the next major problem involves analytically prescribing which angle is the most appropriate for the system's visual display. If it is determined that viewing angle does indeed affect distance perception, and if a function can be described that relates the two, the next step would be to specify a decision rule for determining which angle to use. On the surface, there are two possible criteria for choosing a particular angle of view:

1. Choose the angle which engenders the most veridical perception.

2. Choose the angle which engenders distance perception that most closely matches real-world (non-veridical) perception.

The first criterion is easily specified: the viewing angle which engenders a linear function with a slope of 45° and an intercept of zero should be selected (Figure 2-1).

The second criterion is more difficult to specify. Although there is a surfeit of psychological literature on how distance is perceived (dating back to Bishop Berkeley's work at the beginning of the 18th century), there is a dearth of specific information on real-world perception of distances over the range that is relevant to this project, i.e., 0m to 1,000m. (A variety of studies have examined distance perception with artifical stimuli, such as line drawings and abstract shapes or natural objects, but over a rather limited range of distance.) Enough data have been collected, however, to begin deriving a function relating judged distance with actual distance. Gibson and her associates (Gibson and Bergman, 1954; Gibson, Bergman, and

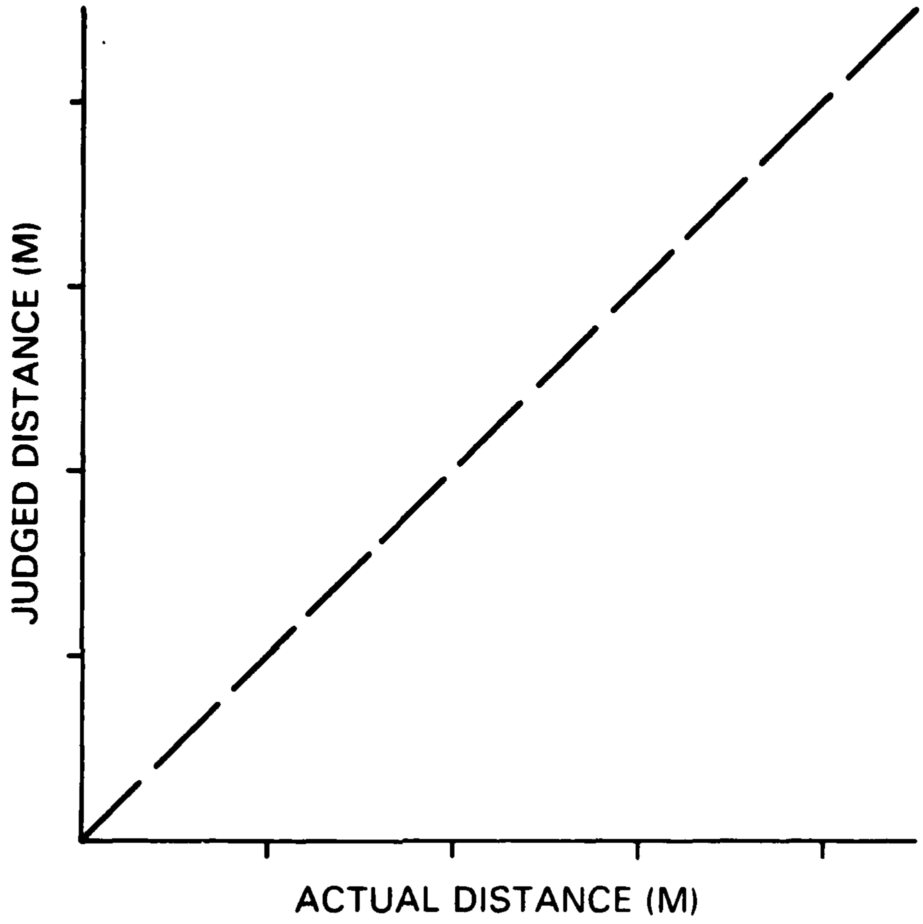

Figure 2-1
VERIDICAL PERCEPTION OF DISTANCE

Purdy, 1955; Purdy and Gibson, 1955), although primarily interested in the effects of training on distance estimates, have obtained rather comprehensive results concerning absolute and relative distance judgments over open terrain with objects up to 400 yards from the observer. Although Gibson did not apply an exponential function, the authors of this report used such a function to summarize her data. Specifically, Stevens' (1951) power law was applied: $J = kA^n$ where J is judged distance and A is actual distance. Data from Gibson, Bergman, and Purdy (1955) were best summarized by a power function with $n = .85$ for distances varying from 52 to 395 yards. This result is consistent with that of Teghtsoonian and Teghtsoonian (1970); for outdoor distance judgments with distance ranging from 5 to 480 feet, a power function with an exponent of .85 best summarized their data. As the range of distances decreased, however, the exponent approached 1.0; i.e., the data were best summarized by a linear function. Stevens (1957) reports an exponent of .67 for visual distance estimation.

Widin (1973a, 1973b) collected distance judgments for the widest range of distances -- from 200m to 2,000m. Again, the authors of this report applied a power function to the data and generated a best fit with an exponent of .86 for Widin (1973a) and .81 for Widin (1973b) for open terrain. Thus, it appears that outdoor distance perception over a wide range of distances is not veridical and can be summarized by a power function with an exponent ranging from .67 to .86.

2.2.3 Distance Perception in Photographs and Natural Terrain - There are a variety of studies examining distance judgments with photographs (e.g., Smith 1958a, 1958b; Smith and Gruber, 1958; Smith and Smith 1961; Liskow, 1979), but few comparing distance judgments in the natural environment to those with photographs. Widin (1973a, 1973b) has conducted

the only empirical examination which makes this comparison with the wide range of distances that are relevant to this project.

In Widin's first study (Widin, 1973a) two groups of recruits from a fire control platoon judged thirty distances ranging from 250m to 1,950m over ground, each group on separate terrain, and judged the same distance in projected photographs. Distance judgments with actual terrain were significantly different than those with the corresponding photographs. Distance perception was surprisingly veridical in both conditions, up to 750m, after which there was increasing underestimation. The authors of this report fit an exponential function to the data from each condition and found an exponent of .86 for the real-world viewing and an exponent of .61 for photographic viewing, indicating a more pronounced attenuation of distance judgments in the photographic condition as distance increased.

Widin's second study (1973b) limited the distance range to approximately 1,000m and found less of a difference between real-world judgments and photographic judgments. Once again, these authors fit a power function to Widin's data and found exponents of .81 and .75 for real-world judgments and photographic judgments, respectively.

The decrease in veridicality of distance perception from the natural environment to photographs has been attributed primarily to the coexistance in pictures of flatness information, as well as depth information (Attneave and Frost, 1969; Gibson, 1971, 1979; Hagan, 1974). Surface texture, motion parallax, and other information specify the picture surface as flat, whereas linear and texture perspective, occlusion, and size cues specify a surface extended in depth. Hagan, Jones, and Reed (1978) have hypothesized, however, that

it is the truncation of the visual field, particularly of the foreground, that is the critical variable accounting for attenuated veridicality with photographic depth perception. Their study compared monocular distance perception across four conditions: 1) normal viewing; 2) slide viewing, in which the visual display was projected onto a movie screen; 3) rectangular truncation, in which the normal view was actually framed in a rectangular slot the same size as the slide projection; and 4) peephole viewing, in which subjects viewed the display through a small aperture. Subjects then judged distances to various objects in the display. Linear functions relating judged distance and actual distance were derived for all four conditions, and the slopes of these functions were then compared. The slope for the normal, untruncated condition was significantly greater than the other three which did not differ. Truncation of the visual field, which is a property of most photographic displays, appears, then, to be a sufficient cause for attenuating distance perception. Hagan et al. (1978) suggest that all photographs and other delimited displays will produce distance distortion to the extent that the foreground from scene to observer is truncated by image size, frame, or viewing aperture.

Widening the angle of view of a visual displav (stretching objects out and presenting more foreground) may not only be used to circumvent other formatting problems but may also to overcome the effects of truncating the visual display.

2.2.4 Determining the Effects of Viewing Angle - The general purpose of Experiment 1 was to describe, empirically, the effects of widening the viewing angle of photographic displays from the "normal " viewing angle (45°) up to the widest possible rectilinear display (104°), and to describe functions relating judged distance to actual distance for a variety of

viewing angles over a broad range of distances. More specifically, this experiment examined the effects of four viewing angles (45°, 72°, 84°, and 104°) on perceived distance of objects depicted in color slides for two types of terrain (lightly wooded and open) over a wide range of distances (0m to 1,000m). Two types of distance estimates were elicited. The primary one involved the viewer imagining that he was in the depicted scene, judging how far away he was from the target objects. The second involved the viewer judging the distance between the two objects in the scene. It was hypothesized that viewing angle would significantly affect the perceived distance between viewer and object, and in the manner specified by the aesthetic film literature -- the wider the viewing angle, the greater the distance judgment. It was also hypothesized that the perceived distance between objects in the scene would remain unaffected by changes in viewing angle.

2.3 Method

Subjects. Twenty-four students at George Mason University were paid five dollars an hour to serve as subjects. Subjects were run in five groups of two to six, and there were approximately equal numbers of males and females.

Stimuli and Apparatus. A total of forty standard 35mm color slides were used, four apiece from ten separate locations in Virginia, North Carolina, and South Carolina. Four of the locations were in lightly wooded terrain, four were in open terrain, and two were on hilltops. At each of the ten locations, the four separate shots differed with respect to focal length of the camera lens. The four focal lengths and the corresponding angles of view were as follows: (1) 48mm (48°), (2) 28mm (72°), (3) 24mm (84°), and (4) 17mm (104°). Each slide contained three naturally occurring target objects, one at each of three distances -- near, mid-range, and far. For

lightly wooded terrain, near was defined as 0m - 50m, mid-range as 50m - 100m, and far as 100m - 250m. For open terrain and hilltops, near was defined as 0m - 150m, mid-range as 150m - 450m, and far as 450m - 1,000m.

The slides were arranged in four sets of ten with each of the ten locations represented once in each set. Each set was preceded by a slide giving a title for that set. In addition, there was a practice set comprised of a title slide and two practice slides, one of lightly wooded terrain and one of open terrain.

A Kodak Carousel slide projector was used to project the slides onto a screen. Subjects recorded their responses on prepared data sheets.

Procedure and Design. Each subject viewed forty slides. While each slide was presented, the experimenter pointed out each depicted object whose distance was to be judged by the subjects. Subjects were told to put themselves "in the scene, taking the picture" and to judge each target object's distance from their position in the scene. In addition, with the slides of lightly wooded terrain, subjects were required to judge the distance between two depicted objects. After all the subjects in a group responded, the next slide was presented. This procedure was repeated until all forty slides were presented. The slides were presented in one of four orders by varying the sequence of the four different sets of ten: (1) Sets 1, 2, 3, 4; (2) Sets 2, 3, 4, 1; (3) Sets 3, 4, 1, 2; and (4) Sets 4, 1, 2, 3.

Although distance judgments were recorded for two hilltops, these data were not analyzed in this study. Of primary concern were the distance judgments for the two major types

of terrain, lightly wooded and open. The major independent variables analyzed in this study were terrain (lightly wooded or open), distance to object (near, mid-range or far), and viewing angle (48°, 72°, 84° and 104°). Object distance was nested within terrain type.

For most of the analysis, data from each of the two types of terrain was treated separately, as two different experiments. The general design was a 2 (terrain) by 4 (viewing angle) within - subjects design with three levels of object distance nested within terrain. That is, all subjects viewed all the stimuli.

2.4 Results and Discussion

A summary of the principal results is given in Table 2-1. There was a highly significant effect of viewing angle with lightly wooded terrain: [$F(3,69) = 53.07$, $p < .0001$, $MSe = 2116.1$] and with open terrain [$F(3,69) = 11.37$, $p < .0001$, $MSe = 109{,}048.3$]. As viewing angle was widened, judgments of distance from observer to target object increased correspondingly, supporting the general notions of film theorists concerning viewing angle.

The effect of distance was significant: for lightly wooded terrain [$F(2,46) = 104.51$, $p < .0001$, $MSe = 16{,}130.5$] and for open terrain [F(2,46 = 27.31, $p < .0001$, $MSe = 476{,}607.$]. The interaction between distance and viewing angle was significant for lightly wooded terrain [$F(6,138) = 14.50$, $p < .0001$, $MSe = 1046.7$] and for open terrain [$F(6,138) = 7.05$, $p < .0001$, $MSe = 32{,}545.4$]. Finally, there was no significant effect of order in either the lightly wooded condition [$F(3,69) = 2.13$, $p > .1$, $MSe = 4782.2$] or the open condition [$F(3,69) = 1.21$, $p > .3$, $MSe = 70347.9$].

Table 2-1. JUDGED DISTANCE AS A FUNCTION OF TERRAIN, ACTUAL DISTANCE, AND VIEWING ANGLE

	Mean Judged	Mean Actual
I. Lightly Wooded Terrain		
Near Distance (0m to 50m)		32.25
o 45	17.86	
o 72	24.95	
o 84	29.02	
o 104	38.77	
Mid-Range (50m to 100m)		69.50
o 45	41.00	
o 72	56.20	
o 84	64.13	
o 104	83.49	
Far Distance (100m to 250m)		184.50
o 45	115.95	
o 72	147.71	
o 84	161.21	
o 104	196.93	
II. Open Terrain		
Near Distance (0m to 150m)		48.00
o 45	31.43	
o 72	42.72	
o 84	50.86	
o 104	80.66	
Mid-Range (150m to 450m)		205.00
o 45	105.05	
o 72	147.97	
o 84	163.56	
o 104	254.43	
Far Distance (450m to 1000m)		613.75
o 45	276.30	
o 72	369.95	
o 84	457.29	
o 104	544.98	

Figures 2-2 and 2-3 graphically summarize the distance judgments for each of the four viewing angles in lightly wooded terrain and open terrain, respectively. Figure 2-4 presents judged distance as a function of actual distance merged over terrain type. The dashed line in these figures represents the performance of a perfectly veridical perceiver.

A non-linear regression analysis was performed, using a Stevens' power function to describe the relationship between judged distance and actual distance. The power function which was applied was $J = kA^n$ where J is judged distance and A is actual distance. Table 2-2 presents the values of the parameters, k and n, for each of the four viewing angles. The Gauss-Newton method for fitting non-linear regression functions was employed in this analysis (Hartley, 1961).

Table 2-3 shows the means for the between-object judgments in lightly wooded terrain. The effect of viewing angle was not significant [$F(3,69) = .75$, $p > .4$, $MSe = 11.36$], nor was the interaction between distance and angle [$F(9,69) = .89$, $p > .5$, $MSe = 11.36$]. It appears, then, that although the perceived distance of objects in the depth plane is significantly affected by viewing angle, the perceived distance of objects in the frontal plane is not. Put in different terms, these results suggest that an inappropriate choice of viewing angle may induce the user to make errors when judging how long it takes to get from one location to another or how far away a particular location is, but <u>will</u> allow for the user to judge correctly if he can move through the gap between two large objects situated in front of him.

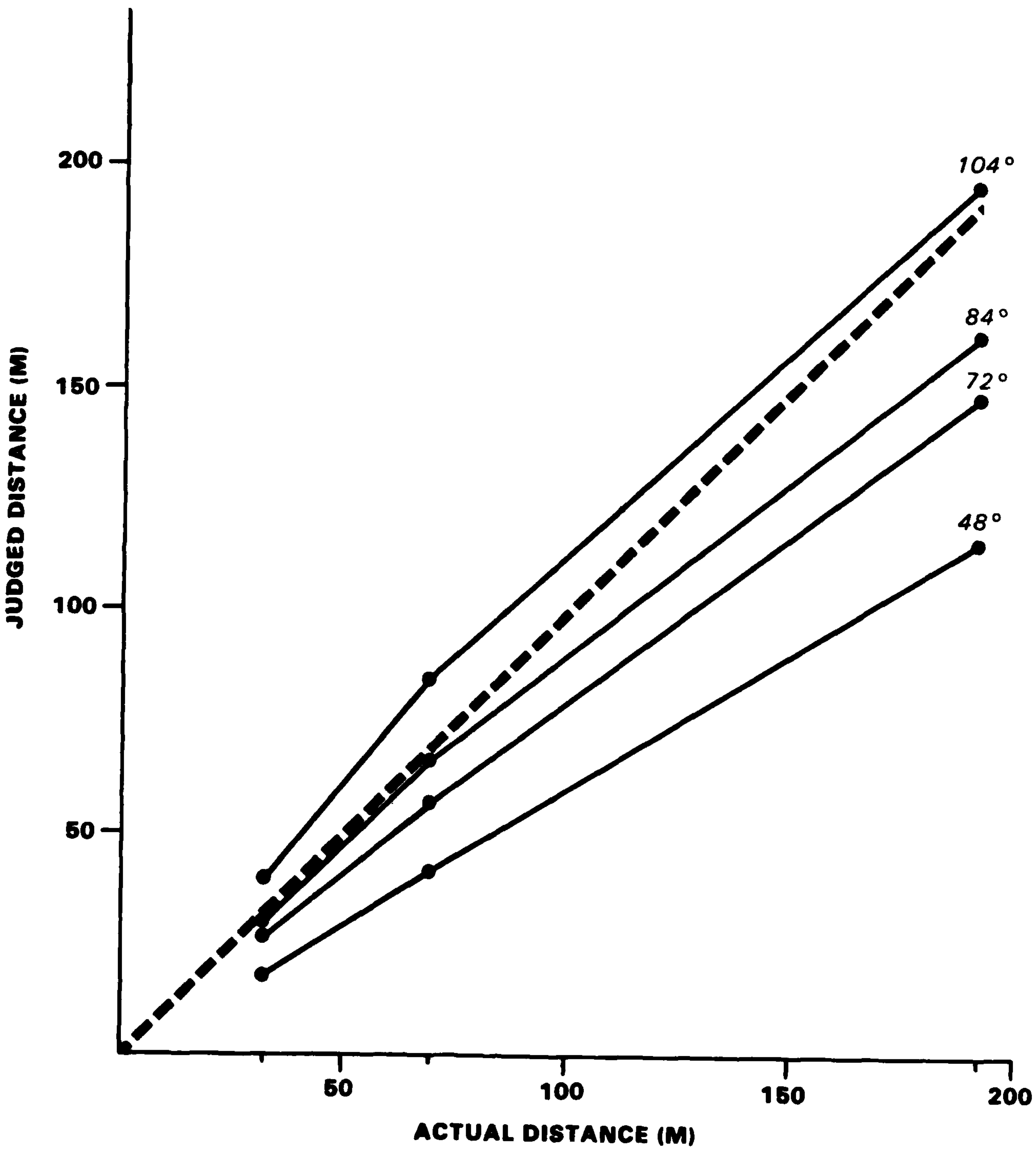

Figure 2-2. DISTANCE PERCEPTION IN LIGHTLY WOODED TERRAIN AS A FUNCTION OF VIEWING ANGLE

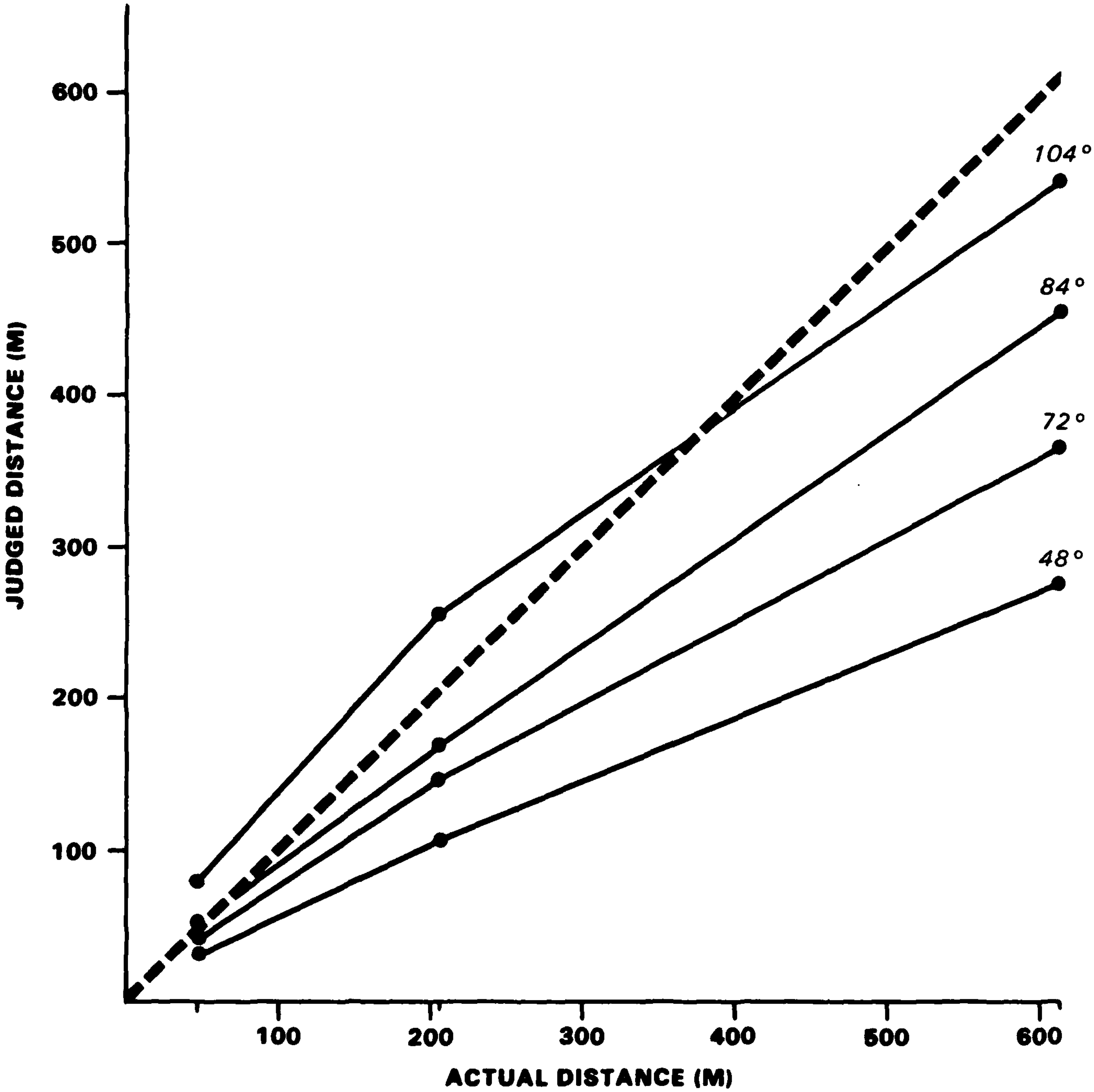

Figure 2-3. DISTANCE PERCEPTION IN OPEN TERRAIN AS A FUNCTION OF VIEWING ANGLE

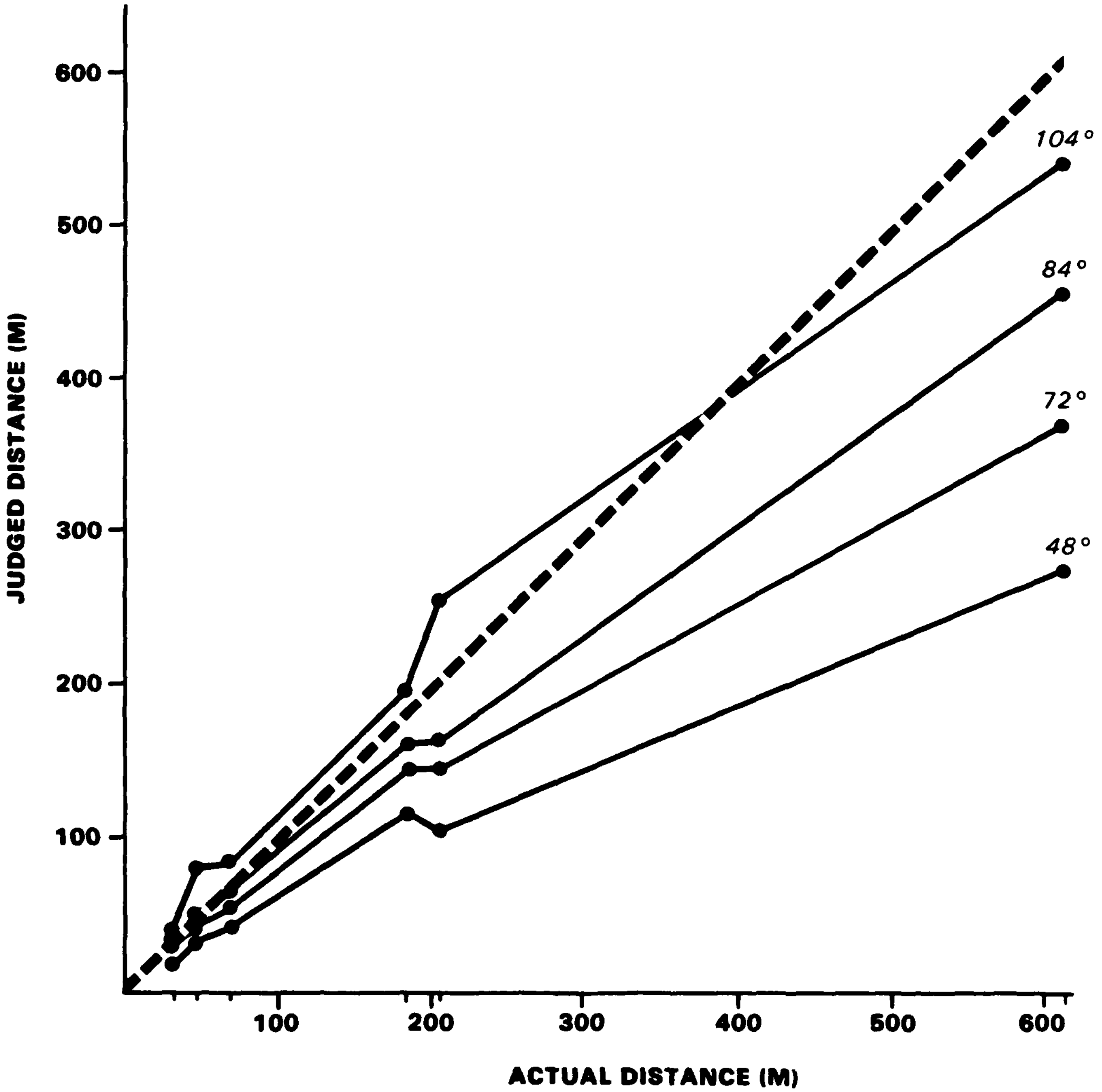

Figure 2-4. DISTANCE PERCEPTION AS A FUNCTION OF VIEWING ANGLE

Table 2-2. ESTIMATION OF PARAMETERS FOR $J = kA^n$

Angle of View	n	k
45°	.83	1.31
72°	.84	1.77
84°	.89	1.43
104°	.79	3.22

Table 2-3. JUDGED DISTANCE BETWEEN THE TWO DEPICTED OBJECTS AS A FUNCTION OF VIEWING ANGLE

Viewing Angle	Mean Judged Distance (m)
48°	9.90
72°	9.70
84°	9.58
104°	10.08

3.0 EXPERIMENT 2: THE EFFECT OF VIEWING ANGLE ON THE PERCEPTION OF HILLS

3.1 Abstract

In Experiment 2, the effect of viewing angle and visual travel on the perceived steepness and height of depicted hills was examined. Steepness perception was significantly affected by viewing angle and by visual travel over the terrain. When subjects viewed hills from a distance and up close, wider viewing angles tended to elicit lower steepness estimates. Further, after visually traveling to the hills, subjects' steepness estimates increased significantly, independent of viewing angle.

This experiment also demonstrated that height perception can be affected by viewing angle: when viewers were visually on a hill, viewing angle significantly affected height perception; when the hill was viewed from a distance, perceived height remained constant across the different viewing angles. In addition, viewing angle significantly affected perceived distance to the hills, whereas ratings of travel quality and climbing experience were unaffected by viewing angle.

3.2 Background

As demonstrated in Experiment 1, increasing the viewing angle of photographic material significantly and predictably affects visual perspective, making objects in the depth plane appear more distant. It has also been observed in pilot studies, conducted by Kraft and Patterson (1981), that widening the viewing angle may affect the perception of <u>hills</u>, making them appear farther away, lower, and less steep than they actually are. Furthermore, these observations suggested that with a

wide viewing angle, the perception of a given hill can actually change as the viewer visually travels toward that hill. From a distance, the hill may look small and flat, but as the viewer approaches it may seem to become larger and steeper.

Examining the perception of hills is of paramount importance for a number of reasons. First, from the standpoint of software design, it would be highly desirable to photograph hills with the camera on the level, i.e., perpendicular to a plumb line. Overlaying dynamic and static targets onto the videodisc imagery is far more tractable with vertical camera angle held constant. Second, in order to depict visually the cresting of a hill, the horizon must move down the picture frame, simulating the ascent of a hill. A level camera maximizes this effect. Pilot work has shown that to keep the camera level and accommodate those hills that a tank can navigate, it is necessary to employ viewing angles that are larger than the normal 45° angle. It is important, then, to discover the perceptual effects on hills of these wider viewing angles. Finally, in terms of tank tactics, hills are of the utmost importance. A tank commander must be able to judge how navigable a hill is and must be able to implement relatively precise maneuvering near the top of the hill. These three areas of concern--system design, movement perception, and tactics--all point to research on the perception of hills.

Experiment 1 was performed in order to examine the effect of viewing angle on static distance estimates. Experiment 2 extends Experiment 1 by examining dynamic displays and by investigating the perception of hills. The primary issue of interest in Experiment 2 was how perceived steepness of hills was affected by changes in viewing angle and how the experience of visual travel toward the hills affected estimates of steepness. It was hypothesized that if a hill was particularly shallow (15° or less) or particularly steep (50° or more), the

viewing angle may not have much effect; but if a hill was in the normal range of perceptibly traversable grades (15° to 40°), then viewing angle may indeed affect perceived steepness. Another measure of steepness, aside from direct estimation--a more qualitative measure--was the subject's judgment of whether or not a jeep could traverse a given hill. This measure was not expected to reveal any profound empirical insights, but rather was employed to support the findings from the direct steepness judgments and to provide some real-world validity to experimental tasks, tying it to the ultimate product of this research--a system which allows visual travel over natural terrain.

In addition, Experiment 2 was designed to examine other perceived characteristics of the hills as a function of viewing angle. More specifically, the purpose of this research was to examine distance perception, height perception before and after traveling toward the hills, and subjective estimates of the quality of travel and of climbing, all as a function of viewing angle.

The analysis of the results of Experiment 2 then involved four separate issues: (1) steepness perception as reflected by direct steepness estimates before and after visually traveling to the hills and by traversability estimates, (2) height perception, (3) distance perception, and (4) estimates of the dynamic quality of visual travel and climbing.

3.3 Method

Subjects. Twenty-four students at George Mason University were paid five dollars an hour to serve as subjects. Subjects were run in five groups of from three to six subjects, and there were approximately equal numbers of males and females.

Stimuli and apparatus. Twenty-four separate linear sequences of 35mm slides were used, four sequences at each of six different hills located in Virginia, North Carolina, and South Carolina. At each of the six hills, the four separate sequences differed only with respect to the focal length of the camera lens used to photograph the hill. The four focal lengths and the corresponding angles of view were as follows: (1) 48mm (48°), (2) 28mm (72°), (3) 24mm (84°), and (4) 17mm (104°).

The six hills were categorized with respect to three different levels of steepness, two apiece at each steepness level. Two of the hills had an average grade of 15°, two had an average grade of 35° and two had an average grade of 50°. The steepness, height, and initial distance for each of the six hills is shown in Table 3-1.

Four sequences of slides were constructed for each of the six hills. Each sequence consisted of 35mm slides taken at distances approximately 5m apart so that sequential presentations constituted movement toward and onto the hill. For any one hill, each sequence of slides represented one of the four visual angles; 48°, 72°, 84°, or 104°. A set of stimuli, then, consisted of one representation, or sequence, for each of the six hills. There were four sets of stimuli. In each set, the order of presentation for the hill sequences was randomly assigned, as was the viewing angle for each hill. There were two constraints on this random assignment: (1) no hill could begin more than one set, and (2) for any two adjacent sets of six hills each viewing angle had to be represented three times. In addition to the six target hill sequences, one practice sequence was constructed.

Special forms were constructed to capture subjects' responses. Each form had three blocks of questions concerning a given hill. The first block recorded four initial judgments:

Table 3-1. DIMENSIONS OF THE SIX HILLS

	Hill	Mean Steepness	Height (ft.)	Distance (m)
LT	1	15°	18	75
LL	2	15°	21	100
ST	3	35°	25	70
Man	4	35°	35	120
HI	5	50°	30	130
GI	6	50°	50	85

(1) the perceived distance to the top of the hill, (2) the perceived height of the hill, (3) the initial perceived steepness of the hill, and (4) whether or not a jeep could be driven up the hill. The next block recorded the post-travel judgments: (1) the perceived steepness after traveling to the hill and (2) the perceived height after traveling to the hill. The final block had the subjects rate on a seven-point scale: (1) the experience of "travel" and (2) the experience of ascending the hill. In addition, the steepness-level guide was prepared which showed six different steepnesses ranging from a 10° grade to a 60° grade by increments of 10°. This guide for judging steepness level is shown in Figure 3-1.

Two Kodak Carousel Slide Projectors connected to a Model 2 Kodak Carousel Dissolver were used to project the slides onto a screen. The dissolver presented the slides in sequence with no blank time on the screen, thereby inducing a sensation of jerky visual movement from one slide to the next.

Procedure and design. All subjects received practice on judging a hill's distance, height, steepness, and traversability. Each group of subjects then viewed all twenty-four hill sequences. While the first slide in each sequence was presented, each subject made four initial judgments concerning the hill: (1) distance to the top, (2) height, (3) steepness, and (4) whether or not a jeep could be driven up the hill. The next hill-sequence which was presented showed visual travel up to and part of the way up a hill. Subjects then made a second steepness judgment and a second height judgment. They were told not to record a second judgment if the hill looked the same as it did initially. Next, the hill-sequence was completed and the subjects rated (on a seven-point rating scale) the overall experience of travel and of ascending the hill. After all the subjects in a group responded, the next slide was presented. This procedure was repeated until all twenty-four sequences were presented.

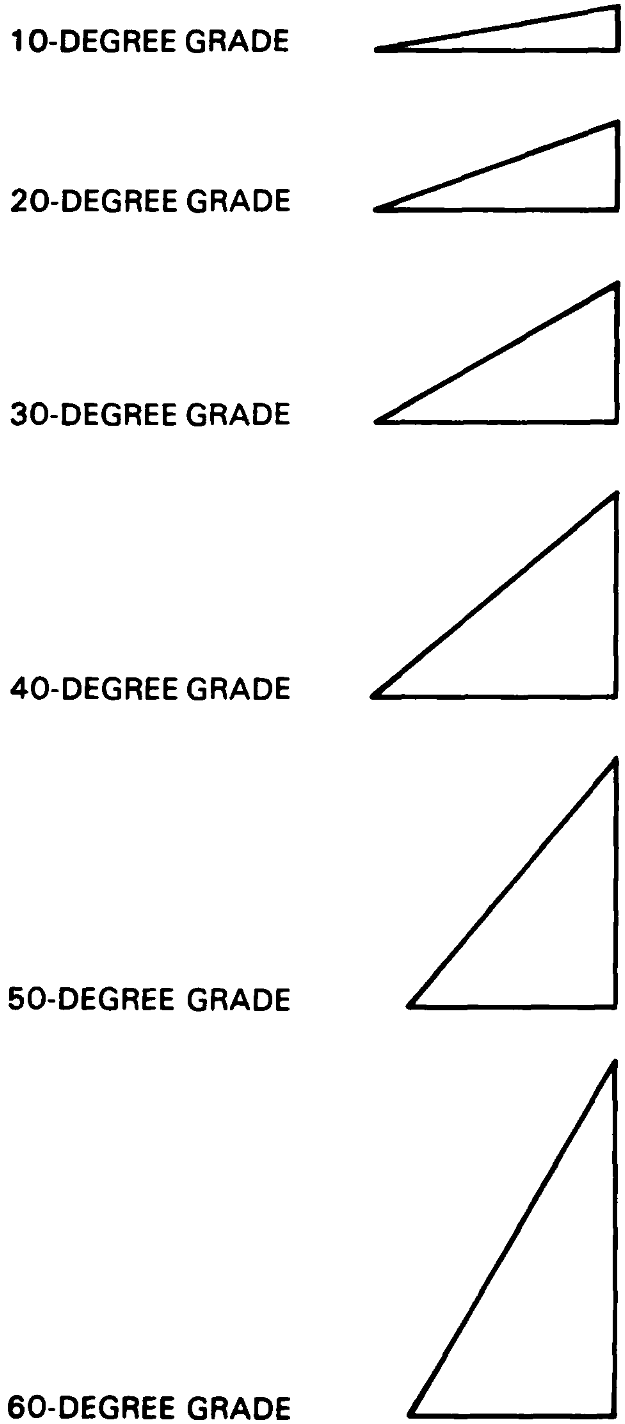

Figure 3-1
A GUIDE FOR JUDGING STEEPNESS LEVEL

The twenty-four hill sequences were presented in one of four orders by varying the sequence of the four sets of six: (1) sets 1, 2, 3, 4; (2) sets 2, 3, 4, 1; (3) sets 3, 4, 1, 2; and (4) sets 4, 1, 2, 3.

The primary dependent variable was the judgment of steepness for the three different levels of actual steepness. The major independent variables affecting judged steepness were actual steepness of the hills (15°, 35°, and 50°), occurrence of the judgment (pre and post-travel), and angle of view (48°, 72°, 84°, and 104°). The complete design for judged steepness was a six (hill sequence) by four (angle of view) by four (presentation order) by three (steepness level) by two (judgment occurrence) design, with hill sequence, angle of view, steepness level, and judgment occurrence representing within-subjects manipulations and presentation order representing a between-subjects manipulation.

Of secondary concern was judged height. The major independent variables affecting this judgment were actual height of the hills (18', 21', 25', 30', 35', and 50'), occurrence of the judgment (pre and post-travel), and angle of view (48°, 72°, 84°, and 104°). The complete design for judged height was a six (actual height) by four (presentation order) by four (angle of view) by two (occurrence of judgment) design with actual height, angle of view, and judgment occurrence representing within-subjects manipulations and presentation order representing a between-subjects manipulation.

The judgment of distance to the tops of the hills represented a replication of Experiment 1. The independent variables affecting perceived distance were actual distance (70m, 75m, 86m, 100m, 120m, and 130m), and angle of view (48°, 72°, 84°, and 104°).

Perceived traversability of the hills was examined as a function of actual steepness and angle of view. Ratings of travel quality were examined as a function of actual distance and angle of view, while ratings of climbing experience were examined as a function of actual steepness and angle of view.

3.4 Results and Discussion

3.4.1 Judged steepness - A summary of the principle results is given in Table 3-2. For the initial steepness judgment, there was a highly significant effect of actual steepness [$F(2,46) = 76.55$, $p < .001$, $MSe = 443.6$], but not of viewing angle [$F(3,69) = 2.33$, $p > .05$, $MSe = 49.9$]. The interaction between actual steepness and viewing angle was not significant [$F(6,138) = 1.08$, $p > .3$, $MSe = 58.9$].

Although the effect of viewing angle was not significant, it did approach significance: $p < .08$. A careful examination of Table 3-2 reveals that the viewing angle manipulation showed a strong trend in the predicted direction with the shallow and medium grades: perceived steepness decreased as viewing angle increased. No such trend was apparent for the steep 50° grade. In order to quantify the apparently differential effects of viewing angle across levels of steepness, Duncan's multiple range test (Keppel, 1973) was applied within each steepness level. Indeed, significant differences were found with the 35° grade: the 72° view and the 104° view produced significantly flatter steepness judgments than the normal 48° view ($p < .05$). No other differences were observed.

After the subjects made the initial steepness judgment for a given hill, they visually traveled toward the hill and part of the way up. Then, they made a second steepness judgment. The means for these judgments are presented in the second column in Table 3-2. Note that when subjects

Table 3-2. JUDGED STEEPNESS AS A FUNCTION OF STEEPNESS LEVEL AND VIEWING ANGLE

	Initial Judged Steepness	Final Judged Steepness	Difference
15-degree grade			
o 45	15.15	19.50	4.35
o 72	13.48	20.50	7.02
o 84	13.23	18.77	5.54
o 104	12.85	20.60	7.75
35-degree grade			
o 45	35.44	42.73	7.29
o 72	32.35	37.65	5.29
o 84	33.33	38.52	3.73
o 104	30.96	37.60	6.65
50-degree grade			
o 45	38.54	39.21	0.67
o 72	39.13	41.98	2.85
o 84	40.06	39.08	-0.98
o 104	38.92	36.71	-2.21

left the second judgment blank, it meant that they perceived the steepness to be the same as in the initial judgment. Thus, each non-response on the second steepness judgment assumed the value of the corresponding initial steepness judgment.

Again, there was a large, significant effect of actual steepness [$F(2,46) = 72.02$, $p < .0001$, $MSe = 332.5$]. Further, there was a significant effect of viewing angle [$F(3,69) = 2.97$, $p < .05$, $MSe = 50.7$] and a significant interaction [$F(6,138) = 3.27$, $p < .01$, $MSe = 60.3$].

Duncan's multiple range revealed that, for the 35° grade, the three wide viewing angles (72°, 84°, and 104°) produced significantly flatter steepness estimates than the normal 48° view ($p < .05$); and for the 50° grade, the 104° view produced significantly flatter steepness judgments than the 72° view.

The third column in Table 3-2 shows the mean difference between the initial and final steepness judgments. These difference results were particularly fecund, engendering several different lines of analysis.

The first and most basic analysis consisted of a simple t-test, comparing pre-travel and post-travel estimates of steepness. This difference was significant at the .001 level, indicating that steepness perception changed as the viewer visually moved over the terrain.

The next line of analysis focused upon the effect of viewing angle and actual steepness on the differences between pre and post-travel steepness judgments. There was a large, significant effect of actual steepness [$F(2,46) = 15.12$, $p < .0001$, $MSe = 155.0$], a non-significant effect of viewing angle [$F(3,69) = 1.66$, $p > .1$, $MSe = 47.21$], and a significant interaction [$F(6,138) = 3.60$, $p < .005$, $MSe = 43.6$].

Finally, Duncan's multiple range test was conducted, revealing that the 50° grade produced significantly smaller differences between pre and post-travel steepness judgments than either the 15° grade or the 35° grade. It appears, then, if a hill is steep enough, it specifies the same information about its grade regardless of whether the viewer is far away or up close. To support this observation, separate t-tests were conducted with each level of steepness. As expected, there was a significant change in steepness perception before and after travel, for the 15° grade and the 35° grade ($p < .0001$), but not for the 50° grade ($p > .9$).

3.4.2 Judged height - Table 3-3 presents the initial height judgments as a function of actual height and viewing angle. (Note that the minor discrepancies between the mean values and the values in the corresponding rows and column, are due to missing values in the original data.) There was, of course, a highly significant effect of actual height [$F(5,115) = 27.58$, $MSe = 190.6$, $p < .0001$]; the effect of viewing angle was not significant [$F(3,69) = 1.46$, $MSe = 103.5$, $p > .2$]. It appears, then, that height relationships within the pictured scene are unaffected by changes in angle of view. There was a significant interaction between actual height and viewing angle [$F(15,331) = 1.88$, $MSe = 101.3$, $p < .05$].

Table 3-4 presents the final height judgments as a function of actual height and viewing angle. There was, again, a highly significant effect of actual height [$F(5,115) = 18.99$, $MSe = 180.6$, $p < .0001$] and a significant interaction between actual height and viewing angle [$F(15,331) = 2.17$, $MSe = 82.7$, $p < .01$].

There was also a significant effect of viewing angle [$F(3,69) = 2.75$, $MSe = 115.7$, $p < .05$]. It appears that when photographs were taken on a hill, the wider viewing angles

Table 3-3. INITIAL JUDGED HEIGHT AS A FUNCTION OF ACTUAL HEIGHT AND VIEWING ANGLE

Actual Height (ft.)	Viewing Angle				
	48°	72°	84°	104°	Mean
18	14.5	11.3	8.6	7.0	10.4
21	10.2	10.6	12.9	10.0	10.9
25	16.6	18.1	16.7	19.4	17.7
30	20.3	25.5	22.4	25.0	23.3
35	28.4	27.9	19.3	21.2	24.2
50	30.8	26.0	27.7	30.5	28.8
Mean	20.1	20.0	18.0	18.9	

Table 3-4. FINAL JUDGED HEIGHT AS A FUNCTION OF ACTUAL HEIGHT AND VIEWING ANGLE

Actual Height (ft.)	Viewing Angle				
	48°	72°	84°	104°	Mean
18	16.5	14.8	11.2	9.0	12.9
21	10.9	17.0	14.7	10.0	13.2
25	18.3	20.0	17.0	19.9	18.8
30	19.3	24.5	21.2	24.6	22.4
35	26.1	26.2	22.5	20.6	23.9
50	33.6	26.2	26.1	26.2	28.0
Mean	20.8	21.5	18.7	18.5	

(84° and 104°) tended to decrease perceived height. This significant effect of viewing angle on perceived height when the viewer was "on" the hill may have been due to the lack of any pictorial height information other than the hill itself against the sky. That is, when the hill was perceived from a distance, as it was in the initial judgment, the viewer may have based his perception of height on the relationship between the hill and the surrounding terrain. In this situation, there was height constancy across different viewing angles. However, when the viewer was visually on the hill, as he was during the final height judgment, there was no comparative information about relative height within the depicted scene. In the absence of such information, the viewer may have put himself into the scene (as he did with the distance judgments in Experiment 1) and judged height based upon his relationship to the crest of the hill. This relationship changed as viewing angle was widened, and the final height judgments reflected this change.

Table 3-5 presents judged height as a function of actual height and judgment occurrence (i.e., pre or post-travel). There was a significant effect of actual height on the difference between pre and post-travel height estimates [$F(5,115) = 3.30$, $MSe = 62.9$, $p < .01$]. The shallower hills appeared steeper up close than at a distance, and the steeper hills appeared shallower up close than at a distance. This difference, however, was slight.

Table 3-6 presents judged height as a function of viewing angle and judgment occurrence, with no significant effect of viewing angle on the difference between pre and post-travel estimates of height [$F(3,69) = 2.69$, $p > .05$].

Table 3-5. JUDGED HEIGHT AS A FUNCTION OF ACTUAL HEIGHT

Actual Height (ft.)	Initial Judged Height	Final Judged Height	Difference
18	10.4	12.9	2.5
21	10.9	13.2	2.3
25	17.7	18.8	1.1
30	23.3	22.4	-0.9
35	24.2	23.9	-.3
50	28.8	28.0	-.8

Table 3-6. JUDGED HEIGHT AS A FUNCTION OF VIEWING ANGLE

Viewing Angle	Initial Judged Height	Final Judged Height	Difference
48	20.12	20.83	0.72
72	20.02	21.53	1.51
84	17.91	18.77	0.86
104	18.98	18.50	-0.48

Most importantly, the overall difference between pre and post-travel estimates of height was <u>not</u> significant ($p > .4$). The perceived height of the hills was not appreciably affected by visual distance from the hill or by movement towards the hill.

3.4.3 <u>Judged distance</u> - Table 3-7 presents perceived distance to the tops of the depicted hills as a function of viewing angle. The effect of viewing angle on distance perception was highly significant [$F(3,69) = 9.01$, MSe = 4,736.5, $p < .0001$]. Again, as in Experiment 1, the perceived distance from the viewer to objects in the scene was predictably and consistently affected by changes in the angle of view.

3.4.4 <u>Perceived traversability</u> - In order to add a sense of realism to the task of judging steepness, as each hill was presented, subjects were asked if they could drive a jeep up the depicted hill. Subjects responded either "yes," "maybe," or "no." Table 3-8 presents these response frequencies as a function of actual steepness of the hills and angle of view. Each of the twenty-four subjects in this experiment viewed two examples of each combination of actual steepness and viewing angle. Therefore, the number of responses in a given row of Table 3-8 cannot exceed forty-eight. (The total for each row is typically less than forty-eight due to missing values.)

Tables 3-9 and 3-10 aggregate over viewing angle and actual steepness, respectively, making their relationships to perceived traversability clearer. Table 3-9 presents perceived traversability as a function of actual steepness. A chi-square analysis of these data showed a significant effect of actual steepness at the .0001 level. Table 3-10 presents perceived traversability as a function of viewing angle. A chi-square analysis of these data showed that the effect of viewing angle was not significant ($p > .8$).

Table 3-7. JUDGED DISTANCE TO HILLTOPS AS A FUNCTION OF VIEWING ANGLE

Viewing Angle	Mean Judged Distance (m)*
48°	80.9
72°	103.8
84°	107.5
104°	126.8

* Mean Actual Distance = 96.8

Table 3-8. TRAVERSABILITY JUDGMENTS

Actual Steepness	Viewing Angle	Can you ride a jeep up the hill? Yes	Maybe	No
15°	48°	42	3	2
	72°	40	4	3
	84	41	0	6
	104°	44	3	0
35°	48°	26	11	9
	72°	29	12	5
	84°	25	17	5
	104°	33	9	6
50°	48°	17	13	17
	72°	13	16	18
	84°	16	12	20
	104°	16	13	19

Table 3-9. PERCEIVED TRAVERSABILITY AS A FUNCTION OF ACTUAL STEEPNESS

	Can you ride a jeep up the hill?		
Actual Steepness	Yes	Maybe	No
15°	167	10	11
35°	113	49	25
50°	62	54	74

Table 3-10. PERCEIVED TRAVERSABILITY AS A FUNCTION OF VIEWING ANGLE

	Can you ride a jeep up the hill?		
Viewing Angle	Yes	Maybe	No
48°	85	28	27
72°	82	26	32
87°	82	29	31
104°	93	25	25

3.4.5 Ratings of travel quality and climbing experience - Travel quality was not significantly affected by viewing angle [$F(3,69) = .077$, $MSe = 1.02$, $p > .5$]. It is hypothesized that at the slow rates of presentation in this experiment--2.5 seconds per slide--travel quality was generally poor and that widening the viewing angle did little to overcome this problem.

The experience of climbing also was not affected by viewing angle [$F(3,69) = 0.16$, $MSe = 1.71$, $p > .9$]. Steepness level, however, did yield a significant effect [$F(2,46) = 12.69$, $MSe = 5.82$, $p < .0001$]. The mean ratings of climbing experience for the 15° grade, the 35° grade, and the 50° grade were 4.79, 4.60, and 3.63, respectively. The lower ratings for the 50° hills were probably an artifact, due to the difficulty of properly photographing ascent of these hills.

4.0 EXPERIMENT 3: COHERENCE OF VISUAL TRAVEL AS A FUNCTION OF LINEAR AND ANGULAR DISPLACEMENT BETWEEN SUCCESSIVE VIEWS OF THE WORLD

4.1 Abstract

The purpose of Experiment 3 was to examine the effect of (1) jump size and (2) number of viewing directions on the coherence of visual travel in two types of terrain. Subjects viewed sequences of slides representing discrete stepwise movement over natural terrain. Their primary task was to indicate the type of movement represented in each sequence (linear, angular, or random) and the extent of movement. The performance on this task was assumed to be a measure of travel coherence. In lightly wooded terrain, travel coherence began to fall apart at jump sizes of 30m; and at 40m, became appreciably worse. In open terrain, travel coherence fell apart at 55m. Angular displacements of more than 15° were incoherent in lightly wooded terrain; however, in open terrain, coherence was maintained even with 30° angular displacements.

4.2 Background

A videodisc-based training system providing visual travel over natural terrain will demand considerable <u>coverage</u> of the represented terrain. The more coverage, the more flexibility and pedagogical value the system will have. The user of such a system must be provided with enough terrain to explore so that he will not collide with the limits of his visual world. This system must also provide the user with <u>coherent visual movement</u> as he explores the terrain. That is, the environment must be sampled sufficiently to allow for coherent and compelling visual travel.

In an ideal world, it would be easy to provide the user with both wide coverage and high-quality visual travel. However, due to the storage constraints inherent in videodisc technology, the amount of information which can be presented is limited. Given a fixed number of videodisc frames, there is a direct tradeoff between terrain coverage and travel quality. Increasing the rate at which the environment is sampled will increase travel quality, but decrease coverage. Decreasing the sampling rate will allow for greater coverage at a cost to travel quality. It is necessary, then, to identify the appropriate levels of coverage and travel quality. For the ATR system, coverage will be specified by tactical considerations, but travel quality must be defined with respect to the human perceiver, through psychological investigation. The general purpose of this experiment, then, is to examine empirically the perception of visual movement in the context of the ATR system.

Two variables which have a profound effect on the quality of visual movement are: (1) jump size--the distance between the center of one grid unit and the center of the next grid unit on a particular path of travel, and (2) number of viewing directions--the number of discrete views resulting in a 360° pivot around the center of a grid unit. That is, as the user visually travels over the terrain, moving in a straight line from one discrete view of the world to the next, he should perceive a coherent flow of movement. Further, as the user scans the environment, receiving successive discrete views around a 360° pivot, he must be able to perceive a coherent sense of angular movement.

It is important to note the distinction between coherence and continuity of the visual display. Webster's New Collegiate Dictionary (1980 ed.) defines coherence in this way: "to... fit or stick together in a suitable or orderly way." Continuity

is defined as: "uninterrupted connection, succession. . ." These definitions are suitably close to the application in question; that is, at a minimum, the ATR system must maintain coherence--the user must be able to make sense of the visual display and, at a maximum, provide continuity (i.e., an experience of smooth, uninterrupted travel over the display terrain). There is a continuum, then, of potential visual experience that could be provided by this system. Suppose a motion picture is taken of the terrain. This would certainly provide a continuous display. Suppose, then, that every other frame in the filmstrip is removed: the film would still provide visual continuity, albeit uneven. If fifteen out of every sixteen frames were removed, the display would probably no longer maintain continuity, but would continue to provide coherence. Finally, if ninety-nine out of every one hundred frames were removed, the display may no longer maintain coherence and the viewer may get lost while traveling in a straight line (Lippman, 1980). Thus, it is evident that coherence and continuity correspond to two portions of a continuum, ranging from unrelated successions of pictures to smooth movie-like travel, with the experience of continuity demanding higher resolution than the experience of coherence.

This experiment is concerned with <u>travel coherence</u>. The goal is to determine the point at which coherence breaks down, both in straight-line travel and pivots, thus providing boundary values below which the system parameters cannot go. This experiment defines the lower limits of perceptual acceptability with regard to travel quality. More specifically, it will determine the maximum linear jump size and the maximum angular displacement that maintains coherence on straight-line travel and pivots, respectively.

4.3 Method

Subjects. Twenty-four students at George Mason University were paid five dollars an hour to serve as subjects. Subjects were run in five groups of three to eight and there were equal numbers of males and females.

Stimuli and apparatus. Thirty-two different six-shot sequences of 35mm slides were constructed for use as stimuli. The initial shot (Slide 1) in each sequence was presented as an establishing shot. The next three shots (Slides 2-4) represented front views of straight-line travel taken at 10m increments from the initial shot. These first four shots represented the lead-in to the two test shots (Slides 5 and 6). The spatial displacements represented by the fifth and sixth shots were varied in the manner described below.

Each sequence was defined by the type and size of the displacements between the fourth and fifth shots and between the fifth and sixth shots. There were two types of systematic displacement, with four levels of each type: four levels of linear displacement and four levels of angular displacement. These eight levels of systematic displacement were nested within two types of terrain: lightly wooded and open. Table 4-1 presents the level of systematic displacement for each type of terrain. In every sequence containing a systematic displacement between the fourth and fifth shots, the sixth shot bore exactly the same relationship to the fifth as the fifth to the fourth. That is, there was a duplication of each systematic displacement within a sequence. There were sixteen such sequences constructed for this experiment: four levels of linear displacement and four levels of angular displacement for each of two types of terrain.

Table 4-1. TYPES OF SYSTEMATIC DISPLACEMENT

Lightly Wooded Terrain

Linear Displacement	Angular Displacement
L1 = 10m	A1 = 7.5°
L2 = 20m	A2 = 15°
L3 = 30m	A3 = 22.5°
L4 = 40m	A4 = 30°

Open Terrain

Linear Displacement	Angular Displacement
L1 = 15m	A1 = 7.5°
L2 = 35m	A2 = 15°
L3 = 55m	A3 = 22.5°
L4 = 75m	A4 = 30°

In addition, there were sixteen other sequences constructed wherein there was a random displacement between the fourth and fifth shots. That is, after photographing the four-shot lead-in, the camera was moved to a randomly selected location in the same piece of terrain, such that it bore no visible relationship to its original location. The sixth shots in the random-displacement (RD) sequences were systematically related to the fifth shots, matching identically the sixteen different levels of displacement in the sixteen systematic-displacement (SD) sequences. The structure of the thirty-two test sequences is presented on Table 4-2. There were, then, four different types of displacement combinations represented in these thirty-two sequences: linear-linear (LL), angle-angle (AA), random-linear (RL), and random-angle (RA).

Each of the thirty-two sequences was photographed in a different section of terrain. Equal numbers of RD and SD sequences were constructed so as not to induce response bias on the basis of the stimuli. Further, of the angular displacements, there were equal numbers of right and left turns.

In addition to the thirty-two test sequences, four practice sequences were constructed. These four practice sequences represented examples of the four different types of displacement combinations: linear-linear (LL), angle-angle (AA), random-linear (RL), and random-angle (RA).

Two sets of travel sequences were assembled with sixteen sequences per set. The sixteen sequences in the first set were randomly selected with the stipulation that each set of the sixteen levels of displacement had to be represented once in that set. The order of presentation was randomly assigned. The remaining sixteen sequences comprised the second set. The second set was ordered in the same fashion as the first.

Table 4-2. STRUCTURE OF THE THIRTY-TWO TEST SEQUENCES

LIGHTLY WOODED TERRAIN			OPEN TERRAIN		
Sequence	Displacement 1 (Shot 4-Shot 5)	Displacement 2 (Shot 5-Shot 6)	Sequence	Displacement 1 (Shot 4-Shot 5)	Displacement 2 (Shot 5-Shot 6)
1	10m	10m	17	15m	15m
2	20m	20m	18	35m	35m
3	30m	30m	19	55m	55m
4	40m	40m	20	75m	75m
5	7.5°	7.5°	21	7.5°	7.5°
6	15°	15°	22	15°	15°
7	22.5°	22.5°	23	22.5°	22.5°
8	30°	30°	24	30°	30°
9	Random	10m	25	Random	15m
10	Random	20m	26	Random	35m
11	Random	30m	27	Random	55m
12	Random	40m	28	Random	75m
13	Random	7.5°	29	Random	7.5°
14	Random	15°	30	Random	15°
15	Random	22.5°	31	Random	22.5°
16	Random	30°	32	Random	30°

A special form was constructed to capture subjects' responses, as shown in Figure 4-1. The large box on the left half of the page was used to record the perceived systematic relationships in displacements 1 and 2. The first four hashmarks, labeled 1-4, represented the first four slides and the three arrows represented the lead-in of three 10m increments. Subjects drew an arrow along the hashmarks, starting with the mark labeled "4", if they perceived a linear displacement. If they perceived an angular displacement, they drew a line in the semicircle. The length of each subject's arrow or the degree of angular disparity between the subject's line and the dotted line in the semicircle indicated the extent of the perceived linear displacement or angular displacement, respectively. The numbers to the left of the hashmarks mark off 10m increments.

The box in the upper right portion of the score sheet (Figure 4-1) was used if the subject perceived a random displacement followed by a systematic displacement. If the fifth shot was perceived as not having a relationship to the fourth, subjects put an "X" in the "5TH SHOT DON'T KNOW" box. If they then perceived a systematic relationship between the fifth and sixth shots, they indicated the type and extent of displacement on the hashmarks or in the semicircle of the upper right-hand box. If, however, subjects perceived no systematic relationship between the fifth and sixth shots, they put on "X" in the "6TH SHOT DON'T KNOW" box.

Two Kodak Carousel Slide Projectors connected to a Model 2 Kodak Carousel Dissolver were used to project the slides onto a screen. The dissolver presented the slides in sequence with no blank time on the screen, thereby inducing a sensation of jerky visual movement from one slide to the next.

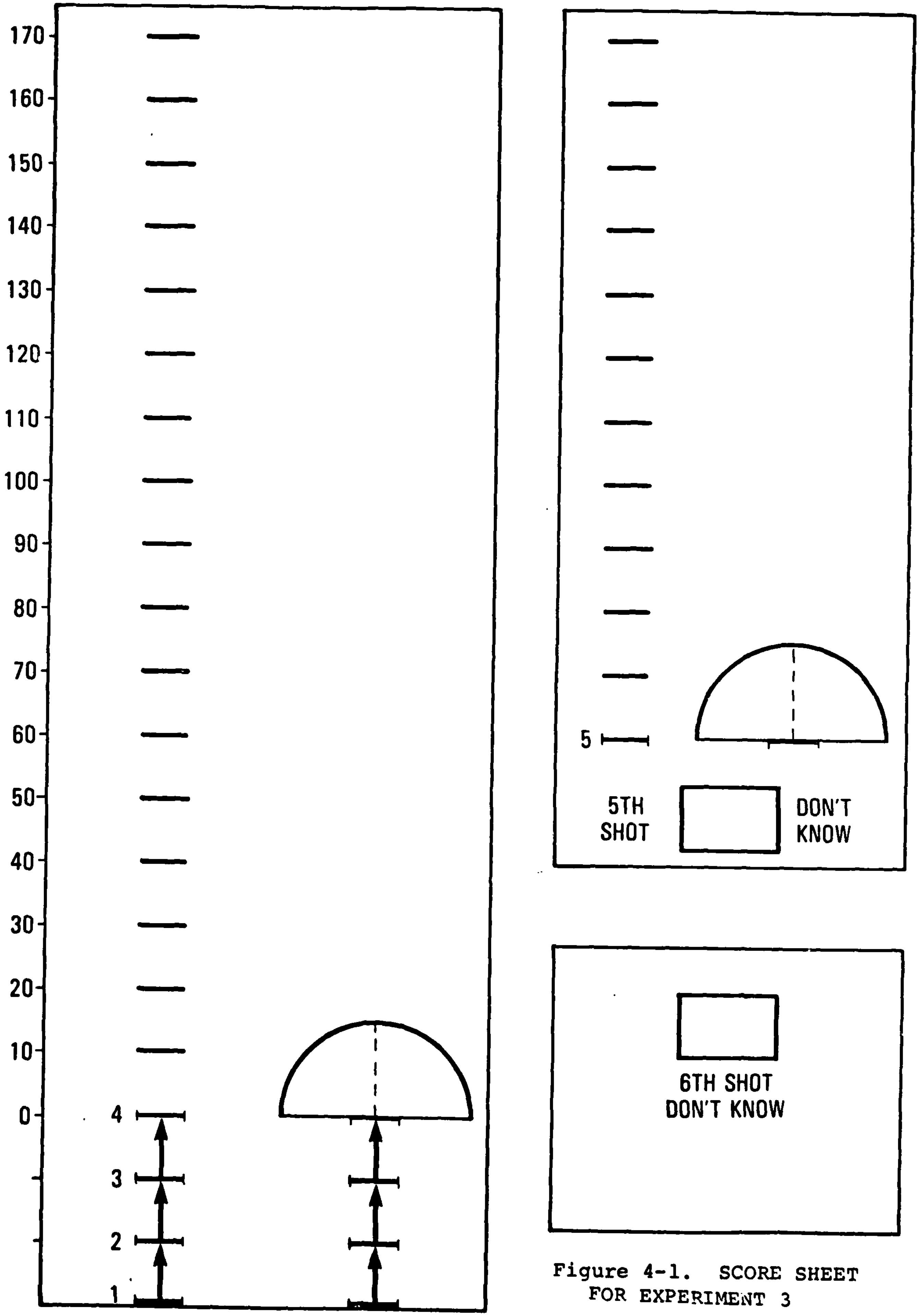

Figure 4-1. SCORE SHEET FOR EXPERIMENT 3

Procedure and Design. All subjects received practice with the four types of spatial displacement represented by the slide sequences: LL, AA, RL, and RA. Each group of subjects then viewed all thirty-two six-shot travel sequences. Immediately after the fifth slide in each sequence was presented, subjects recorded their responses on a scoresheet such as the one in Figure 4-1. Subjects indicated the type and extent of displacement by drawing an arrow of the appropriate length along the hashmarks in the left box to specify linear displacement. A line appropriately displaced from the dotted line in the semicircle in the left box was drawn to specify angular displacement. Or an "X" was placed in the "5TH SHOT DON'T KNOW" box in the upper right corner to specify random displacement. After all the subjects in a group responded, the sixth and final shot of the sequence was presented. Subjects then indicated the type and extent of the displacement between the fifth and sixth shots. If subjects saw a systematic relationship between the fourth and fifth shots and between the fifth and sixth shots, they recorded both responses in the left box. If subjects saw no direct relationship between shots four and five, but did between shots five and six, they made their second response in the upper right box, indicating the type and extent of that second displacement: Note that in this case, their first response was an "X" in the "5TH SHOT DON'T KNOW" box in the upper right. If no relationship was seen between the fifth and sixth shots, subjects put an "X" in the "6TH SHOT DON'T KNOW" box. After all the subjects in a group responded, the next travel sequence was presented. This procedure was repeated until all thirty-two sequences were presented.

The primary dependent variables were (1) perceived type, and (2) perceived amount of displacement for the first and second displacement judgments. Perceived type and perceived amount were examined separately in the following way: Each examination consisted of four separate analyses, as shown in

Table 4-3. Within each of these four analyses, the first and second displacement judgments were analyzed separately and also pooled. The random sequences (RL and RA) were used primarily as a stimulus-defined basis for subjects to specify that they truly "don't know" the relationship between successive shots in the sequences. The random sequences simply established validity for the subjects to indicate they did not see any direct relationship between successive shots. For this reason, data from the RL and RA sequences were not examined.

4.4 Results and Discussion

4.4.1 Perceived type of displacement - In the context of ATR, it would not be meaningful to compare angular displacements (AD) with linear displacements (LD). The purpose of the LD manipulation was to determine the maximum linear jump size allowable in the ATR system. The purpose of the AD manipulation was to determine the number of discrete views needed to specify a coherent 360° pivot for a given grid location. The two manipulations--LD and AD--focused on two different system parameters: jump size and number of views, respectively. Therefore, they were analyzed separately.

Further, it is not necessary to make empirical comparisions between lightly wooded terrain and open terrain because the ATR system allows the two types of terrain to be formatted differently. In developing the system, the two terrain types will be treated as separate design issues. Direct empirical comparisons are not meaningful. Determining the design characteristics of each is more informative than making comparisons between the two.

As shown in Table 4-3, separate analyses were conducted for each of the two types of displacement and for each of the two types of terrain.

Table 4-3. ANALYSES ON PERCEIVED DISPLACEMENT (TYPE AND AMOUNT)

		TERRAIN TYPE	
		Lightly Wooded Terrain	Open Terrain
DISPLACEMENT TYPE	Linear	Analysis 1	Analysis 2
	Angular	Analysis 3	Analysis 4

All the analyses of perceived displacement type involved a frequency count of the number of observations in each judgment category (linear, angular, or random) for each of the four levels of displacement across all subjects. The prototype structure for each of the analyses is shown in Table 4-4. For each test displacement, the value within each cell represents the number of subjects out of twenty-four that responded with a particular judgment of displacement type. The specific method employed to analyze these data was based on the methodology proposed by Grizzle, Starmer, and Koch (1969). It uses generalized least squares to produce minimum chi-square estimates, modeling functions, or categorical responses in a linear fashion.

It should be noted that all the frequency matrices analyzed herein yielded <u>overall</u> chi-square values which were significant beyond the .01 level. The overall chi-square analyses were not of interest in this experiment, however, and are not reported in this document. Of importance were 1) the effects of linear and angular displacement and 2) the <u>specific levels of displacement</u> at which travel coherence fell apart and gave way to perceptual confusion.

4.4.1.1 <u>Linear displacement</u> - Table 4-5 presents the judgments for the first linear displacement (LD1), the second linear displacement (LD2), and the two displacements combined for lightly wooded terrain. A chi-square analysis yielded a significant effect of displacement level [$x^2(6) = 36.4$, $p < .001$]. The effect of displacement occurrence (LD1 vs LD2) was not significant [$x^2(2) = 1.18$, $p < .5$]; nor was the interaction between displacement occurrence and displacement level [$x^2(6) = 1.62$, $p < .9$], indicating a similar pattern of results for LD1 and LD2.

Table 4-4. ANALYSES OF PERCEIVED DISPLACEMENT TYPE

Actual Displacement	Perceived Displacement		
	Straight	Angle	Random
D1			
D2			
D3			
D4			

Table 4-5. PERCEIVED DISPLACEMENT TYPE FOR LINEAR DISPLACEMENTS IN LIGHTLY WOODED TERRAIN

Judgments for First Linear Displacement

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
10	24	0	0
20	22	2	0
30	17	7	0
40	11	4	9

Judgments for Second Linear Displacement

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
10	24	0	0
20	22	2	0
30	21	2	1
40	11	1	12

Combined Judgments

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
10	48	0	0
20	44	4	0
30	38	9	1
40	22	5	21

Of particular importance was the pattern of responses across displacement levels. A careful examination of Table 4-5 reveals that the perception of linear displacement began to break down at a jump size of 30m. Subjects continued to perceive some sort of relationship between successive shots taken at 30m increments, but they were less likely to specify the correct type. They knew that the relationship was not random--only one of forty-eight responses indicated no relationship--but they began to confuse the linear displacement with an angular one.

At a linear jump size of 40m, travel coherence clearly broke down, with over half the responses specifying a non-linear relationship. At 40m, nearly half the responses indicated no relationship at all between successive shots.

For the 30m jump size, Table 4-5 indicates that simply the disruptive nature of changing from 10m increments (shots 1-4) to a 30m increment (shots 4-5) may have led several subjects to perceive a non-linear change. That is, in LD1, seven subjects perceived the 30m linear displacement as non-linear, whereas in LD2, only four subjects saw it as non-linear. This difference between LD1 and LD2 at 30m was slight, however.

In summary, for lightly wooded terrain, the perception of coherent linear travel began to fall apart at a jump size of 30m and became markedly worse at a jump size of 40m. Given these results, it would be appropriate to set the maximum allowable jump size in lightly wooded terrain at 25m.

Table 4-6 presents the judgments for LD1, LD2, and the two displacements combined for open terrain. A chi-square analysis yielded a significant effect of displacement level [$x^2(6) = 12.4$, $p < .05$]. The effect of displacement

Table 4-6. PERCEIVED DISPLACEMENT TYPE FOR LINEAR DISPLACEMENTS IN OPEN TERRAIN

Judgments for First Linear Displacement

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
15	22	2	0
35	24	0	0
55	13	2	9
75	23	1	0

Judgments for Second Linear Displacement

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
15	22	2	0
35	24	0	0
55	19	4	1
75	24	0	0

Combined Judgments

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
15	44	4	0
35	48	0	0
55	32	6	10
75	47	1	0

occurrence was not significant [$x^2(2) = .52$, $p > .7$] nor was the interaction between displacement occurrence and displacement level [$x^2(6) = 2.92$, $p > .8$], indicating a similar pattern of responses for LD1 and LD2.

An examination of Table 4-6 reveals an enigmatic pattern of results. In open terrain, as expected, the 15m jump provided coherent linear travel, as did the 35m jump. However, the first 55m jump provided far less coherent travel then the 75m jumps. It is hypothesized that a sampling problem may occur when photographing linear travel in open terrain at increments of greater than 50m. For example, if there are no significant landmarks which disappear between successive shots, linear travel in open terrain may be presented with a jump size of up to 75m (or greater) and still maintain coherence. However, if a significant landmark disappears completely or if the general terrain characteristics change from one shot to the next, coherence can be disrupted. The likelihood of failing to sample a landmark increases as the distance between successive shots increases. With the stimuli in this experiment, it appears as if a significant landmark disappeared from view during the first 55m jump, and coherence was disrupted. No such change occurred in the 75m jump, and subjects were able to maintain coherent travel. It should be noted that the second displacment of 55m yielded far more coherence than the first. In the first 55m jump, nine subjects failed to see a coherent relationship between successive shots. During the second 55m jump, subjects were able to readjust and, with only one exception, perceive at least some sort of relationship between shots.

In summary, for travel in open terrain, coherence may break down at jump sizes of 50m or greater, but can be maintained at much greater jump sizes given a rather homogeneous stretch of terrain. Based on these results, it

would be prudent to set the maximum allowable jump size in open terrain at 50m.

4.4.1.2 Angular displacement - Table 4-7 presents the judgements for the first angular displacment (AD1), the second angular displacement (AD2), and the two displacements combined for lightly wooded terrain. A chi-square analysis yielded a significant effect of displacement level [$x^2(6) = 25.32$, $p < .001$]. The effect of displacement occurrence was not significant [$x^2(2) = .09$, $p > .9$]; nor was the interaction between displacement occurrence and displacement level [$x^2(6) = 5.22$, $p > .5$], indicating a similar pattern of responses for AD1 and AD2.

Table 4-7 shows that there was a marked break in pivot coherence between 15° and 22.5°. At 22.5°, 40% of the responses indicated a non-angular displacement, whereas at 15°, less than 15% indicated a non-angular displacement. At 22.5°, however, subjects knew there was some sort of relationship between successive shots since only three of forty-eight responses indicated a random displacement. However, many confused the angular displacement with a linear one. At an angular displacement of 30°, the number of random responses increased significantly, indicating that many subjects saw no relationship at all between successive shots. It should also be noted that there was a slight improvement from AD1 to AD2 at 22.5°.

Given the results of Table 4-7, it might be best to allow a maximum angular displacement of no more than 15° in lightly wooded terrain. The minimum number of views needed to specify a 360° pivot, then, would be twenty-four.

Table 4-7. PERCEIVED DISPLACEMENT TYPE FOR ANGULAR DISPLACEMENTS IN LIGHTLY WOODED TERRAIN

Judgments for First Anuglar Displacement

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
7.5°	0	24	0
15°	2	21	1
22.5°	10	13	1
30°	4	16	4

Judgments for Second Angular Displacement

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
7.5°	3	21	0
15°	4	20	0
22.5°	6	16	2
30°	1	16	7

Combined Judgments

	Perceived Displacement		
Actual Displacement (m)	Straight	Angle	Random
7.5°	3	45	0
15°	6	41	1
22.5°	16	29	3
30°	5	32	11

Table 4-8 presents the judgments for AD1, AD2, and the two displacements combined for open terrain. A chi-square analysis yielded non-significant effects for displacement level [$x^2(6) = 3.42$, $p > .7$], displacement occurrence [$x^2(2) = 1.00$, $p > .6$], and the interaction between the two [$x^2(6) = 3.41$, $p > .7$].

It is important to emphasize that displacement level had no significant effect on perceived displacement type. Furthermore, the data presented in Table 4-8 show a remarkably similar pattern of results for each of the four levels of actual displacement. Perception of displacement type in open terrain was as accurate with the 30° displacements as it was with the 7.5° displacements. Based on these results, it is difficult to set a maximum allowable angular displacement in open terrain. Apparently, 30° angular displacements represent coherent pivots. Perhaps, in open terrain, consideration of continuity and not coherence will specify the maximum allowable angular displacement in a pivot.

4.4.2 Perceived Amount of Displacement - In the analysis of perceived displacement amount, judgments for the two test displacements in each SD sequence were combined and averaged to give a single value. Each subject, then, received a single, mean score for each SD sequence, and these scores were used as the input in the following statistical analyses. In addition, when subjects recorded the wrong displacement type for a given judgment, that judgment was treated as a missing value in the analysis of perceived amount of displacement. Note that because of these missing values, the degrees of freedom across the various statistical tests will not be exactly the same.

In all cases, there was a highly significant effect of actual displacement amount on judged displacement amount. This effect, however, was not of particular interest here, and

Table 4-8. PERCEIVED DISPLACEMENT TYPE FOR ANGULAR DISPLACEMENTS IN OPEN TERRAIN

Judgments for First Angular Displacement

Actual Displacement (m)	Perceived Displacement		
	Straight	Angle	Random
7.5°	3	21	0
15°	2	21	1
22.5°	1	23	0
30°	1	21	2

Judgments for Second Angular Displacement

Actual Displacement (m)	Perceived Displacement		
	Straight	Angle	Random
7.5°	2	20	2
15°	3	21	0
22.5°	2	18	4
30°	0	22	2

Combined Judgments

Actual Displacement (m)	Perceived Displacement		
	Straight	Angle	Random
7.5°	5	41	2
15°	5	42	1
22.5°	3	41	4
30°	1	43	4

the specific F-test values are not presented in this report. Of more critical concern, was the effect of actual displacement amount on the accuracy of perceived displacement for both lightly wooded and open terrain. Thus, in addition to documenting the values for judged amount of displacement, the following two variables were analyzed: (1) absolute discrepancy between judged and actual displacement and (2) percent discrepancy between judged and actual displacement. Absolute discrepancy was calculated for each subject by taking the absolute value of the difference between judged and actual displacement, and percent discrepancy was calculated for each subject in the following way:

$$\text{Percent Discrepancy} = \frac{\text{absolute discrepancy}}{\text{actual amount of displacement}} \times 100$$

4.4.2.1 Linear displacement - Table 4-9 presents judged linear displacement as a function of actual displacement in lightly wooded terrain. In addition to the mean values for judged amount of displacement, there are the mean values for absolute discrepancy and for percent discrepancy.

There was a significant effect of actual displacement amount on absolute discrepancy [$F(3,44) = 5.32$, $MSe = 26.5$, $p < .01$], indicating that the longer the jump, the more likely subjects were to misjudge the actual size of the jump. However, actual displacement amount did not significantly effect the percentage of discrepancy [$F(3,44) = 1.76$, $MSe = 1018.2$, $p > .1$]. In a relative sense, subjects were no less accurate at judging 40m jumps than they were at judging 10m jumps in lightly wooded terrain. In fact, the 10m jump produced the greatest percent error, largely because of the subjects' tendency to round off their displacement judgments. Note that with

Table 4-9. PERCEIVED AMOUNT OF LINEAR DISPLACEMENT IN LIGHTLY WOODED TERRAIN

Actual Displacement (m)	Mean Judged Displacement (m)	Mean Absolute Discrepancy (m)	Mean Percent Discrepancy
10	14.2	4.2	41.7
20	19.2	4.2	20.8
30	24.4	9.1	30.4
40	36.1	9.4	23.6

all displacement levels other than 10m, the mean judged displacement represented on underestimation of actual displacement.

Table 4-10 presents judged linear displacement as a function of actual displacement in open terrain. There was a significant effect of actual displacement amount on absolute discrepancy [$F(3,53) = 103.92$, $MSe = 46.8$, $p < .0001$], indicating that the longer the jump, the larger the misjudgment of the actual jump size. Further, actual displacement also had a significant effect on percentage of discrepancy [$F(3,53) = 25.97$, $MSe = 202.3$, $p < .0001$]. With all levels of actual displacement, subjects underestimated jump size, but at displacements of 35m and 75m, the underestimations were significantly greater than at 15m and 55m. The smaller percentage discrepancy at 15m may have been due to a floor effect, while the smaller percentage discrepancy at 55m may have been due to additional clutter in the terrain used for the 55m condition. With highly homogeneous terrain, subjects have less of a basis for judging how far they have jumped than with less homogeneous terrain where there are more reference points.

4.4.2.2 Angular displacement - Table 4-11 presents judged angular displacement as a function of actual displacement in lightly wooded terrain. There was not a significant effect of actual displacement on absolute discrepancy [$F(3,37) = 2.09$, $MSe = 23.27$, $p > .1$]. There was, however, a significant effect for percent discrepancy [$F(3,37) = 22.26$, $MSe = 1660.8$, $p < .0001$]. As angular displacement increased, percent discrepancy decreased significantly. The same pattern of effects was evident in open terrain, as shown in Table 4-12. There was, then, a nonsignificant effect of actual displacement on absolute discrepancy [$F(3,50) = 1.45$, $MSe = 56.68$, $p > 2$], but a significant effect of percent discrepancy [$F(3,50) = 6.32$, $MSe = 7984.1$, $p < .01$].

Table 4-10. PERCEIVED AMOUNT OF LINEAR DISPLACEMENT IN OPEN TERRAIN

Actual Displacement (m)	Mean Judged Displacement (m)	Mean Absolute Discrepancy (m)	Mean Percent Discrepancy
15	13.6	3.64	24.2
35	16.2	18.9	53.9
55	44.1	13.6	24.8
75	36.1	38.9	51.8

Table 4-11. PERCEIVED AMOUNT OF ANGULAR DISPLACEMENT IN LIGHTLY WOODED TERRAIN

Actual Displacement	Mean Judged Displacement	Mean Absolute Discrepancy	Mean Percent Discrepancy
7.5°	16.2°	8.8°	118.4
15°	20.9°	7.2°	47.9
22.5°	21.1°	4.6°	20.4
30°	28.6°	5.9°	19.9

Table 4-12. PERCEIVED AMOUNT OF ANGULAR DISPLACEMENT IN OPEN TERRAIN

Actual Displacement	Mean Judged Displacement	Mean Absolute Discrepancy	Mean Percent Discrepancy
7.5°	17.5°	10.0°	183.3
15°	19.2°	6.3°	41.8
22.5°	23.5°	7.7°	34.3
30°	26.7°	5.2°	17.4

Absolute discrepancy remained relatively constant, regardless of the level of angular displacement. It may have been that viewers were unable to perceive <u>fine discriminations</u> in the visually displayed angular movement. Or, alternatively, the score sheets used in this experiment may have made it difficult for the subjects to <u>record</u> the fine discriminations they saw. (See Figure 4-1.) Regardless of the size of the angular displacement, on the average, subjects made errors of 5° to 10° in drawing their lines in the semicircle. It is possible that it may have been more difficult to draw a line in the semicircle accurately specifying a 7.5° pivot than to draw a line accurately specifying a 30° pivot.

4.5 <u>Conclusions</u>

The results for perceived <u>type</u> of displacement were generally more informative than those for perceived <u>amount</u>.

Judgments concerning perceived type clearly indicated that a maximum jump size of 25m was appropriate for lightly wooded terrain. A jump size of more than 25m would lead to a loss of travel coherence such that ATR users might indeed get lost while traveling in a straight line; however, for open terrain, maximum jump size of 50m was suggested. Increases beyond 50m might maintain coherent travel in open terrain, but the likelihood of perceptual incoherence would increase markedly beyond that level.

Judgments concerning perceived displacement type in lightly wooded terrain indicated a maximum allowable angular displacement of 15°. Thus, lightly wooded terrain would demand twenty-four directions of view for specifying a 360° pivot. In open terrain, however, pivot coherence was maintained for angular displacements up to 30°. A best guess for maximum allowable angular displacement in open terrain would be 30°, indicating a need for only twelve directions of view.

5.0 EXPERIMENT 4: NUMBER OF TRAVEL DIRECTIONS FOR ATR

5.1 Abstract

The ATR System must present the user with an experience of free travel while actually maintaining relatively few directions of travel. In Experiment 4 the minimum number of travel directions necessary to provide this sense of free travel was investigated. Subjects viewed film sequences representing linear travel toward a specified object. In each sequence, the actual direction of travel was oblique to the desired direction, and subjects indicated (1) when they first felt uneasy about going astray (R1), and (2) when they felt a strong need to correct their path of travel (R2). The mean value of R1 was approximately 15°, indicating an upper limit of twenty-four travel directions. The mean value for R2 was approximately 22.5°, indicating a lower limit of sixteen travel directions. Terrain had a negligible effect on R1 and no effect at all on R2.

5.2 Background

The videodisc-based surrogate travel system developed by Lippman (1980) presented visual travel over roads, allowing the user to choose among four directions of travel at each intersection. The ATR system described in this document must present visual travel in the open field, allowing the user to travel in virtually any direction. However, because there is a fixed amount of storage on a videodisc and because the ATR system demands wide coverage, the actual number of travel directions must be significantly limited. That is, the ATR system must present the user with the experience that he can travel freely

in any direction while maintaining relatively few actual avenues of movement.

The goal of Experiment 4, then, is straightforward: Specify the minimum number of travel directions that provides an experience of free travel in the open field.

5.3 Method

Subjects. Twenty employees of Decisions and Designs, Inc. served as subjects. Subjects were run individually, with an equal number of males and females.

Stimuli and apparatus. Sixteen separate travel sequences were filmed using a Canon 514XL movie camera. Each sequence presented linear travel over natural terrain. Travel was represented by filming in discrete steps along a straight path similar to the representation of linear travel in the ATR system. The terrain was sampled every 3.33m (i.e,, there was a linear displacement of 3.33m between successive views of the terrain). For each portion of represented terrain, a target object was selected (e.g., a tree or a light pole). However, filming did not proceed toward the target object, but rather the camera was advanced along a path oblique to the one which would lead to the target, as shown in Figure 5-1. Filming was conducted in this fashion to simulate the experience of choosing a particular destination but having to approximate movement toward that destination.

Of the sixteen travel sequences, eight were filmed in lightly wooded terrain and eight in open terrain. In addition, each set of eight sequences was composed of four short and four long travel sequences. And, each set of four consisted of two sequences with an initial angular discrepancy (IAD) of approximately 3.5° (A1) and two sequences with an IAD of

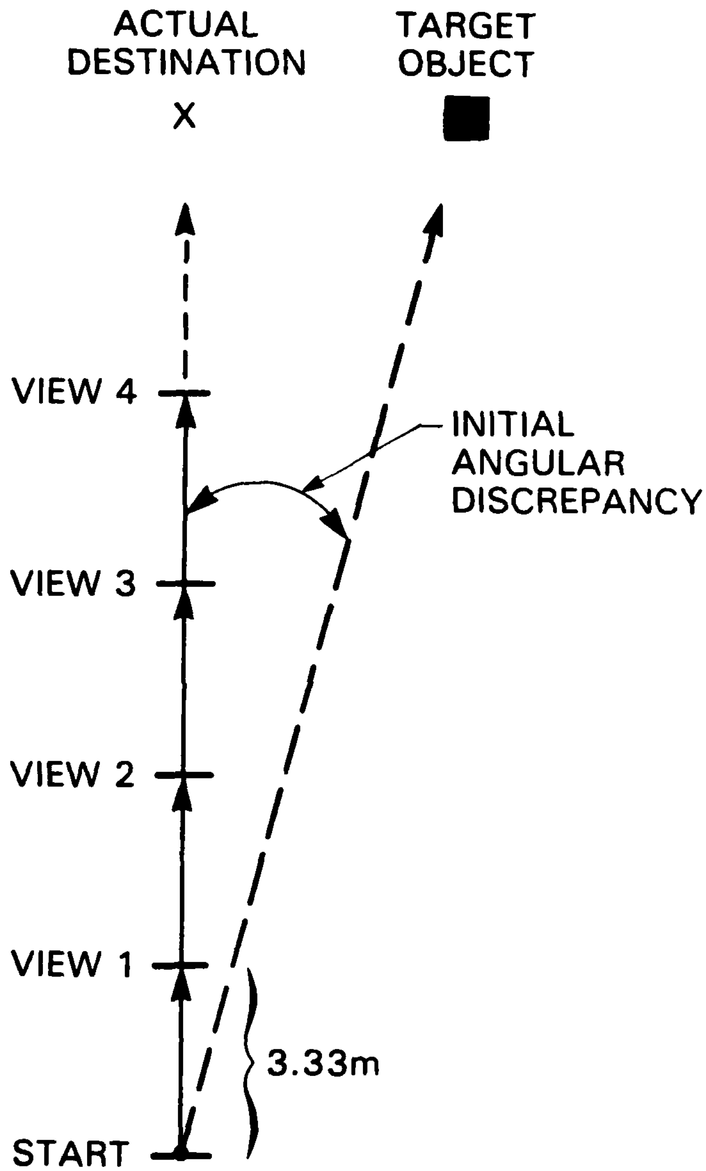

Figure 5-1
FILMING OF THE TRAVEL SEQUENCES

approximately 5° (A2). The design of the stimulus materials is shown in Table 5-1. Each cell in this table was represented by two travel sequences, making a total of sixteen sequences.

In lightly wooded terrain, the average short sequence was 75m and the average long sequence was 110m. In open terrain, the average short sequence was 100m and the average long sequence was 175m. Half the sequences had IADs to the left and half to the right.

The viewing angle of the Canon 514XL used to photograph the terrain was 44°: 22° to the left of the center line and 22° to the right. Thus, the 3.5° IAD represented a 15.9% angular shift from the center line and the 5° IAD represented a 22.7% angular shift from the center line. By calculating the percentage of angular shift from the center line of the visual display, the subjects' responses to the 44° viewing angle could be generalized to other viewing angles.

The sixteen travel sequences were arranged in random order and spliced into one filmstrip. Each sequence was constructed in the following way. First, a 54-frame shot was taken from the starting point (See Figure 5-1). Then, a uniform grey field was filmed for 36 frames. Next, 36 frames were photographed from the starting point again. Then, the camera was moved 3.33m to take a 5-frame shot. The camera was then moved in a straight line another 3.33m and another 5-frame shot was taken, and so on, until the travel sequence was completed. Each sequence was terminated when the designated target object (Figure 5-1) just disappeared from view. Then, fifty-four frames of a uniform grey field were spliced onto the end of each sequence. After this grey field, the next sequence was spliced, and so on, for all sixteen sequences.

Table 5-1. DESIGN OF THE TRAVEL SEQUENCES

Lightly Wooded Terrain

		IAD	
		A1	A2
Sequence Length	Short		
	Long		

Open Terrain

		IAD	
		A1	A2
Sequence Length	Short		
	Long		

In addition to the sixteen test sequences, two practice sequences were constructed in the same fashion as the test sequences. These practice sequences were spliced onto the beginning of the sixteen-sequence filmstrip. The practice sequences could be shown and rewound, and so on, until subjects felt ready to begin the test sequences.

The travel sequences were projected by a Eumig 614D projector onto a white viewing area, approximately 4m from the projector and 3m from each subject. The sequences were presented at a rate of nine frames per second. Thus, the initial 54-frame establishing shot for each sequence was presented for six seconds, followed by 4 seconds of grey field, followed by a 4-second re-establishing shot. Each view in the travel sequence was presented for .55 seconds. With a 3.33m linear jump between shots, travel was simulated at 6m per second or 13.4 miles per hour, the speed a which one might drive a tracked vehicle over open-field terrain.

Procedure and design. Subjects were run individually and each subject received practice on the experimental task until he was confident of his performance. The task was described in the following way. Subjects were told to imagine themselves riding in a vehicle in open-field terrain with someone else driving the vehicle. For each sequence, the experimenter pointed out the target object toward which the subjects wanted to travel. Subjects were warned that, in every case, the "driver" of the vehicle did not know exactly where to go and that he would invariably choose a path that diverged from the desired path. Each subject responded to the travel sequences via a small push-button beeper which was custom-built for the experiment. Subjects were told to use the "beeper" twice during each sequence in order to communicate with the driver of the vehicle. The first beep was meant to communicate when the subject "first felt uneasy about going astray." (Note that this was not a sig-

nal detection task wherein the subject was required to respond immediately upon detecting that the vehicle was deviating from the desired path. Rather, the first beep indicated a sense of uneasiness about visually traveling along other than the desired path of travel. It is assumed that first, the subject detected the deviation and then shortly thereafter, beeped for the first time.)

The second beep was meant to communicate to the driver that "he had better turn (either right or left) or else he would probably drive by and miss the target object."

For each sequence, the experimenter recorded the number of jumps to the subject's first beep and the number to the subject's second beep.

There were two dependent variables of concern in this experiment: the angular shift of the target object from the center of the visual display (1) when the subjects first experienced uneasiness about deviating from the desired path of travel (R1), and (2) when the subjects experienced a strong desire to turn towards the target object so as not to miss it (R2). The major findings of importance were the <u>average</u> overall values for R1 and R2, and the overall <u>range</u> of values for R1 and R2.

Of lesser importance were the effects of the independent variables on R1 and R2. The independent variables were terrain type (lightly wooded or open), length of sequence (short or long), and initial angular discrepancy (3.5° or 5°). The design was a 2 (terrain type) by 2 (angular discrepancy) between-subjects design with 2 levels of sequence length nested within terrain type.

Analysis. Figure 5-2 shows the general framework for the subjects' responses. Note that as the camera moves closer to the actual destination, the target object moves farther away from the center of the field of view (FOV). In this hypothetical example, R1 represents the subject's first beep and R2 represents the second beep. At R1, the target object is approximately 30% over to the left from the center of the FOV. At R2, the target object is approximately 70% over from the center of the FOV. In this example, if the subject had had a 90° angle of view, R1 represents an angular deviation of 13.5° and R2 represents an angular deviation of 31.5° from the center of the FOV.

The direct measure of performance was simply the number of jumps from the start of each sequence to R1 and to R2. This raw measure was then transformed into a more informative measure of performance: percent discrepancy (PD) from the center of the FOV. Figure 5-3 shows how PD was calculated from the number of jumps. (For purposes of clarity, R2 is not shown in Figure 5-3.)

In Figure 5-3, R1 represents the first "beep" of an exemplar subject. The distance from the start of the sequence to R1 is denoted as d_{R1}. The distance to the actual destination is d_a and the distance between the actual destination and the target object is denoted as d_b. The angular shift from the center of the FOV to the target object at R1 (A_{R1}) is calculated in the following way:

$$A_{R1} = \arctan \left(\frac{d_b}{d_a - d_{R1}}\right)$$

If it is assumed, in Figure 5-3 as as example, that d_{R1} is 5 jumps or 16.67m, d_a is 43.3m, and d_b is 12.5m, then A_{R1} is 25.1°.

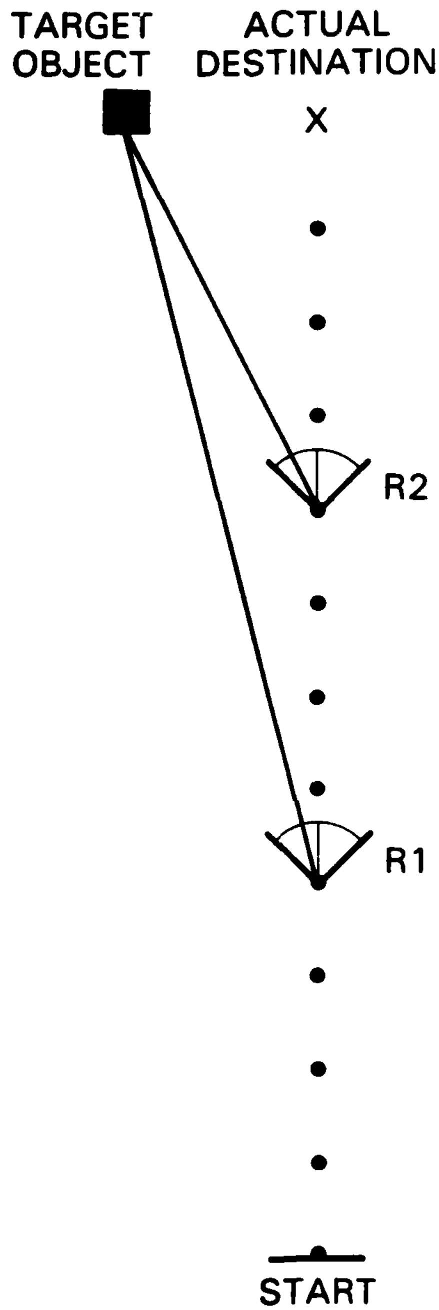

Figure 5-2
RESPONSES TO THE TRAVEL SEQUENCES

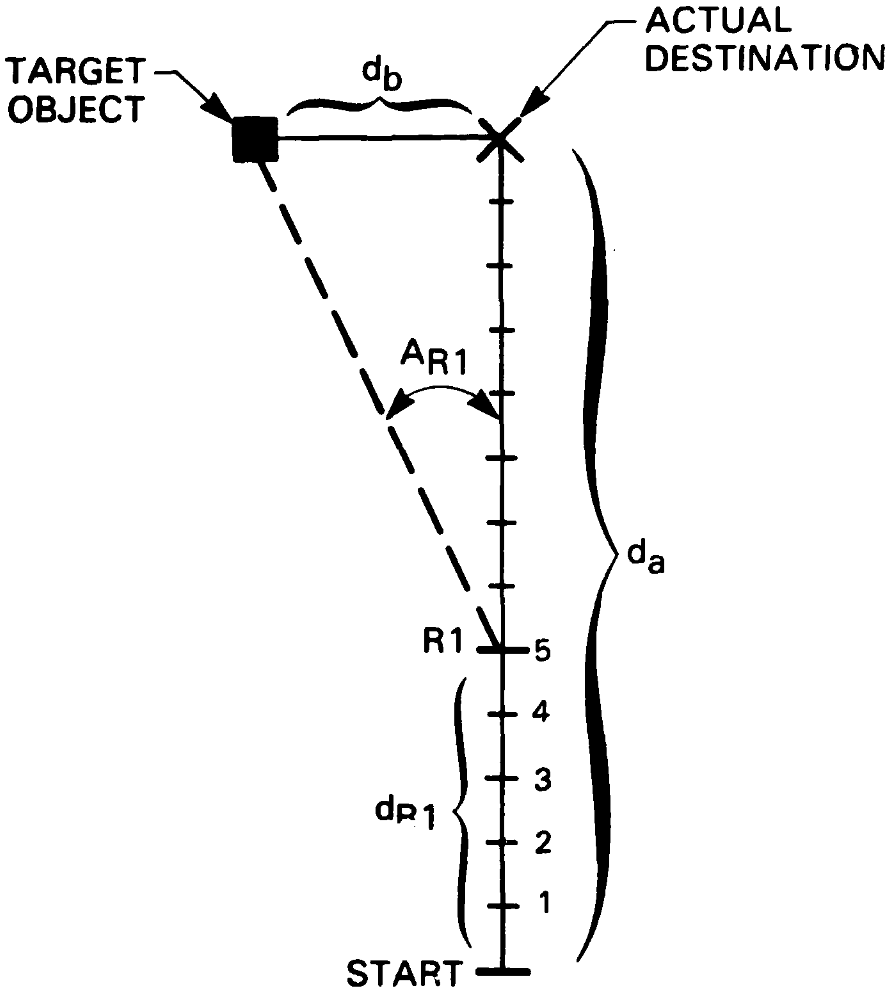

Figure 5-3

CALCULATION OF THE ANGULAR DISCREPANCY BETWEEN THE TARGET OBJECT AND THE CENTER OF THE FOV

Percent angular discrepancy from the center of the FOV (PD) was calculated as follows:

$$PD = \frac{A_{R1}}{.5(\text{viewing Angle})} \times 100$$

The A_{R1} for a 90° viewing angle was calculated as follows:

$$A_{R1-90°} = \frac{PD \times 45°}{100}$$

5.4 Results and Discussion

5.4.1 Overall results - Table 5-2 summarizes the overall statistics for Experiment 4, aggregating over all the conditions. Statistics for percent angular discrepancy and angular discrepancy, given a 90° viewing angle, are shown for R1 and R2. For the remainder of this discussion, the authors of this report will assume that the ATR system will employ a viewing angle of 90°.

Table 5-2 shows that for a 90° viewing angle, on the average subjects would begin to feel uneasy about deviating from their intended path at an angular discrepancy of about 14°. They would experience a strong urge to turn their vehicle at a angular discrepancy of 24°. Note, however, that there is a constraint on the value of the specific angular displacement between adjacent travel directions. Given that the ATR system will have equal angular spacing between travel directions from a given grid center, 360° must be an integer multiple of the number of travel directions. For a 90° viewing angle, the angular displacement that conforms to this constraint and to the average angular discrepancy shown for R1 in Table 5-2, is 15°. Thus, based on the mean R1 response, the ATR system would have paths of travel every 15°, for a total of twenty-four directions

Table 5-2. OVERALL STATISTICS FOR EXPERIMENT 4

		Mean	Standard Deviation	Minimum Value	Maximum Value
Percent Angular Discrepancy	R1	31.1	9.18	12.6	60.3
	R2	54.2	17.13	20.8	100
Angular Discrepancy Given 90° Viewing Angle	R1	13.9	4.13	5.66	27.2
	R2	24.4	7.71	9.4	45

of travel. Based on the mean R2 response, the ATR system would have paths of travel every 22.5°, for a total of sixteen directions of travel.

5.4.2 ANOVA on the effects of terrain, IAD, and sequence length - Table 5-3 shows R1 for a 90° viewing angle as a function of terrain, sequence length, and IAD. There were significant effects for terrain [$F(1,19) = 16.23$, $MSe = 4.9$, $p < .001$], sequence length [$F(1,19) = 12.1$, $MSe = 2.8$, $p < .01$], and IAD [$F(1,19) = 134.3$, $MSe = 4.9$, $p < .0001$]. There was also a significant interaction between IAD and distance nested within terrain [$F(2,38) = 24.8$, $MSe = 7.2$, $p < .0001$]. The interaction between IAD and terrain was not significant [$F(1,19) = 3.91$, $MSe = 3.4$, $p > .05$].

Table 5-4 shows R2 for a 90° viewing angle as a function of terrain, sequence length, and IAD. There was a significant effect of IAD [$F(1,19) = 16.5$, $MSe = 18.1$, $p < .001$]. However, there was not a significant effect of terrain [$F(1,19) = .34$, $MSe = 32.3$, $p > .5$] nor of sequence length [$F(1,19) = .11$, $MSe = 2.07$, $p > .7$]. The interaction between IAD and terrain was significant [$F(1,19) = 16.0$, $MSe = 18.4$, $p < .001$], as was the interaction between IAD and distance nested within terrain [$F(2,38) = 65.7$, $MSe = 10.4$, $p < .0001$].

Of particular interest to ATR is the extremely small effect of terrain on R1 and the lack of any significant effect on R2. Once the target object moved off line an unacceptable amount, subjects responded in a consistent fashion regardless of terrain. It is certainly not the case that open terrain requires fewer directions of travel than lightly wooded terrain.

Table 5-3. R1 FOR A 90° VIEWING ANGLE

Lightly Wooded Terrain

IAD

Sequence Length		A1	A2	Mean
	Short	12.3°	15.9°	14.1°
	Long	11.4°	14.3°	12.9°
	Mean	11.8°	15.1°	13.5°

Open Terrain

IAD

Sequence Length		A1	A2	Mean
	Short	14.7°	14.2°	14.5°
	Long	11.7°	17.3°	14.5°
	Mean	13.3°	15.7°	14.5°

Table 5-4. R2 FOR A 90° VIEWING ANGLE

Lightly Wooded Terrain

IAD

Sequence Length		A1	A2	Mean
	Short	22.3°	25.5°	23.9°
	Long	26.1°	22.9°	24.5°
	Mean	24.2°	24.2°	24.2°

Open Terrain

IAD

Sequence Length		A1	A2	Mean
	Short	24.7°	23.5°	24.1°
	Long	20.5°	29.5°	25.0°
	Mean	22.6°	26.5°	24.6°

5.5 Conclusions

By requiring that each subject respond twice--the first time to indicate initial uneasiness about deviating from the desired travel direction and the second time to indicate a strong desire to correct for this deviation--this experiment established the anchor points along a continuum of perceptual acceptability for limiting the actual number of travel directions in an ATR system. At best, the ATR system should provide enough travel directions so that users never acquire a sense of uneasiness about not going where they want to go. At its worst, the ATR system should simply prevent users from feeling they will miss their desired destination.

Given a 90° viewing angle, twenty-four directions of travel would probably be sufficent to provide the user with a comfortable sense of being able to travel freely in any direction. Sixteen directions of travel, on the other hand, would provide a rather uneasy sense of travel; the user would be well aware that his visual travel was significantly constrained.

In summary, sixteen travel directions would be permissible if technological constraints demanded it, but twenty-four would be far more desirable. Certainly, no fewer than sixteen travel directions should be considered.

6.0 RECOMMENDATIONS FOR FORMATTING THE VIDEODISC IMAGERY

Table 6-1 summarizes the empirically-based recommendations for formatting the ATR videodisc imagery.

The results of Experiment 1 demonstrated that angle of view significantly affected distance perception; the wider the angle, the greater the perceived distance. A viewing angle of 90° was tentatively selected because it represented the widest distortion-free angle, closely approximating distance perception in the real world. It was also demonstrated that perceived distance between two depicted objects was unaffected by viewing angle.

The significant effect of viewing angle upon the perceived steepness of hills, and further, the interaction of visual travel over terrain with steepness perception were the major results of Experiment 2. However, steepness perception appears to be no more variable or distorted with a 90° viewing angle then with any of the viewing angles being considered. Experiment 2 also replicated the results of the first experiment: perceived distance to hilltops was significantly affected by viewing angle; the wider the angle, the greater the perceived distance. In addition, the results of Experiment 2 indicated that when viewers were visually on a hill, viewing angle significantly affected height perception. However, when the hill was viewed from a distance, perceived height was unaffected by viewing angle. That is, if the hill could be compared to the surrounding terrain, there was height constancy across viewing angles.

The examination of the two system parameters shown in Table 6-1, jump size and number of views, was undertaken in

Table 6-1. FORMAT RECOMMENDATIONS BASED ON EMPIRICAL RESEARCH

Format Variable	Parameter Value
VIEWING ANGLE	90°
MAXIMUM ALLOWABLE JUMP SIZE	
Lightly Wooded Terrain	25m
Open Terrain	50m
MINIMUM NUMBER OF VIEWS	
Lightly Wooded Terrain	24
Open Terrain	12
MINUMUM NUMBER OF TRAVEL DIRECTIONS	16 or 24

Experiment 3. For lightly wooded terrain, visual travel remained coherent up to jump sizes of 20m; but it began to fall apart at 30m, and at 40m, was unacceptably poor. Maximum allowable jump size in lightly wooded terrain should be set at 25m. Pivots remained coherent with successive angular displacements of 15°, but became increasingly incoherent with displacements of 22.5° and 30°. Maximum allowable angular displacement in lightly wooded tertain should be set at 15°, indicating that twenty-four viewing directions would be needed to specify a complete 360° pivot.

In open terrain, visual travel remained highly coherent up to jump sizes of 35m. At 55m, travel coherency broke down; but at 75m, a high degree of travel coherence returned. It appears that the greater the jump size, the greater the likelihood that a significant landmark will disappear between successive views, or that the general terrain characteristics will change from one view to the next. Coherent linear travel resumed with a jump size of 75m because the sampled terrain was highly homogeneous. Given the potential loss of coherence that can occur, however, the maximum allowable jump size in open terrain should be set at 50m.

The minumum number of travel directions needed to provide the ATR user with a sense of free travel was investigated in Experiment 4. Subjects viewed film sequences representing linear travel along a path which was oblique to the desired direction of travel. The results suggest that for a 90° viewing angle, subjects will become uneasy about going astray when the angular discrepancy between the desired and actual direction of travel is approximately 15°, indicating an upper limit of twenty-four travel directions. Subjects will experience a strong need to correct their travel path when the angular discrepancy reaches approximately 22.5°, indicating a lower limit of sixteen travel directions. These results apply to both lightly wooded and open terrain.

It should be noted that a non-empirical investigation was conducted concerning image resolution. The results of this investigation indicate that a resolution of 256 X 256 pixels would provide an appropriate amount of detail and texture for the ATR visual display.

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